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EFFECT OF PROLONGED BEDREST AND $+G_z$ ACCELERATION ON PERIPHERAL VISUAL RESPONSE TIME

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16. Abstract

The cardiovascular deconditioning, dehydration, and other physiological changes that occur as a result of prolonged exposure to the zero g space environment raise some questions about the applicability of much previous research which has shown that spacecraft atmosphere reentry accelerations pose no appreciable physiological or performance problems for the astronauts. This report deals with whether or not peripheral visual response time changes during $+G_z$ acceleration following fourteen days of bedrest as well as what effect prolonged bedrest has upon this response. Eighteen test lights, placed 10° arc apart along the horizontal meridian of the subject's field of view, were presented in a random sequence. The subject was instructed to press a button as soon as a light appeared. Response time testing occurred periodically during bedrest and continuously during centrifugation testing. The results indicate that (1) mean response time is significantly longer ($p < 0.01$) to stimuli imaged in the far periphery than to stimuli imaged closer to the line of sight during $+G_z$ acceleration, (2) mean response time at each stimulus position tends to be longer at plateau g than during the preacceleration baseline period for that run by an amount that ranges from about 20 to 120 msec, (3) mean response time tends to lengthen as the g level is increased, (4) peripheral visual response time during $+G_z$ acceleration at 2, 3.2, and 3.8 g was not a reliable advanced indicator that blackout was going to occur, and (5) the subject's field of view collapsed so rapidly just before blackout that the time course of this constriction could not be measured using the present testing technique. The bedrest data showed that the distribution of response times to stimuli imaged across the subject's horizontal retinal meridian remained remarkably constant from day to day during both the bedrest and recovery periods. These findings are discussed in relation to previous studies and to the design and placement of aerospace vehicle instruments.

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SUMMARY

The cardiovascular deconditioning, dehydration, and other physiological changes that occur as a result of prolonged exposure to the zero g space environment raise some questions about the applicability of much previous research which has shown that spacecraft atmosphere reentry accelerations pose no appreciable physiological or performance problems for the astronauts. This report deals with whether normal healthy persons can tolerate $+G_Z$ acceleration levels of 2, 3.2, and 3.8 g after bedrest (supine orientation) for 14 days. Eighteen test lights, placed 10° arc apart along the horizontal meridian of the subject's field of view, were presented in a random sequence. The subject was instructed to press a button as soon as a light appeared. Response time testing occurred periodically during bedrest and continuously during centrifugation testing. The results indicate that (1) mean response time is significantly longer ($p < 0.01$) to stimuli imaged in the far periphery than to stimuli imaged closer to the line of sight during $+G_Z$ acceleration, (2) mean response time at each stimulus position tends to be longer at plateau g than during the preacceleration baseline period for that run by an amount that ranges from about 20 to 120 msec, (3) mean response time tends to lengthen as the g level is increased, (4) peripheral visual response time during $+G_Z$ acceleration at 2, 3.2, and 3.8 g was not a reliable advanced indicator that blackout was going to occur, and (5) the subject's field of view collapsed so rapidly just before blackout that the time course of this constriction could not be measured using the present testing technique. The bedrest data showed that the distribution of response times to stimuli imaged across the subject's horizontal retinal meridian remained remarkably constant from day to day during both the bedrest and recovery periods. These findings are discussed in relation to previous studies and to the design and placement of aerospace vehicle instruments.

INTRODUCTION

Prolonged bedrest is still the best method available for simulating prolonged weightlessness (refs. 1-4). Nevertheless, relatively little research has been carried out on visual (or other sensory) effects of prolonged bedrest.

Three studies have dealt with the effect of bedrest on simple response time (RT). In their first study, Ryback, Trimble, Lewis, and Jennings (ref. 5) measured simple lever pressing RT to the onset of a light for less than 10 min each test session, once a week, for a total of 5 weeks before and 5 weeks after a 5 week-long bedrest period. The subjects stood during these tests. During bedrest, four of the eight subjects were given 200 Kcal of exercise on a total-body ergometer three times a day and 3,334.4 Kcal of nutrients per day.

The rank sum RT scores (presumably inferred from the post-bedrest test data) from the exercise versus the no-exercise (control) group did not differ significantly. Another test (ranked sign), however, in which the data of all eight subjects' pre-bedrest data were compared with their post-bedrest data, indicated significant decrements ($p < 0.01$) (presumably lengthened response times) after bedrest. The authors present a number of possible explanations for their findings, for example, a general debilitating effect caused by reductions in normal activity during bedrest, the result of performing the test while standing upright, the result of lack of practice over the 5-week-long bedrest period and/or transient changes in motivation. These somewhat equivocal findings lead to their second study.

In the second study, Ryback, Lewis, and Lessard (ref. 6) attempted to eliminate the various unwanted effects found in their earlier data. Thus, all RT administrations were given to the subject in the supine position, once each week throughout the 5-week-long bedrest period as well as once each week during the 5-week-long control and 6-week-long recovery periods. The same amount of exercise and caloric intake was given as before. This time no significant RT relationships were found. The authors suggest that the reason bedrest did not affect RT was that administering the test during bedrest acted as "practice," which "inhibited any measurable psychomotor change." Nonetheless, these data appear equivocal for other reasons: (1) there is an apparent lack of control for learning (indeed, many studies have shown that RT does not reach asymptotic value until after several practice sessions (refs. 7-10)), and (2) the relatively small number of trials administered once a week would tend to make interpretation of these data difficult.

Kotovskaya, Vartbaronov, and Simpura (ref. 11) note that after a 70-day bedrest period, the subject's RT tended to lengthen prior to blackout during $+G_x$ centrifuge testing. No other information is given. A more recent study by Leverett, Shubrooks, and Shumate (ref. 12) presented peripheral test lights to monitor for peripheral grayout during $+G_z$ acceleration after one week of bedrest. RT was not monitored and the subject's button-pressing responses were used only to monitor acceleration tolerance. These authors found that "the visual symptoms experienced varied from subject to subject at different G levels. A number of the subjects developed peripheral dimming which persisted throughout a particular run with the central (red) light remaining clear at all times . . . . Most of the subjects experiencing visual problems observed an increase or decrease in the degree of dimming depending upon whether they were in an inspiratory or expiratory phase of respiration . . . . Following the 7-day bedrest episode, all of the subjects who stopped the runs at the various G levels appeared to experience a more rapid loss of vision. That is to say, once dimming of vision became apparent, it was a matter of a few seconds before total visual failure ensued" (ref. 12, p. 91).

The subject of visual function and positive radial acceleration has received a great deal of study over the past several decades; most of it has been summarized elsewhere (refs. 13-18). In addition, eight studies were found that dealt specifically with RT and positive radial acceleration. Each is reviewed in detail in the appendix because of their relevance to the present study.

Despite the many differences between the acceleration profiles, response stimuli, and experimental testing protocol used in the investigations reviewed, it is reasonable to conclude that (1) RT is positively related to $+G_z$ acceleration g level although the effect is relatively small; (2) the visual RT response provides a useful and sensitive indicator of the adequacy of the blood supply to the retina and/or central nervous system (nevertheless, little has been done to isolate the site of grayout and blackout produced by positive acceleration); (3) little has been done to quantify visual RT to stimuli imaged across the field of view during positive acceleration as a possible means of determining

the rate at which the visual field constricts; and (4) much of the RT variability in these studies can probably be traced to differences between subjects, to differences in the testing protocol or equipment used, and/or to differences in the acceleration profiles administered.

No studies could be found to alter Brown and Burke's statement (ref. 19) that "The effect of using test lights which are systematically varied in position from the fovea out into the periphery of the visual field has not been studied. Little or no effort has been made to standardize the retinal location, the area, the luminance, and the spectral character of test lights which are used as the basis of criteria of acceleration tolerance."

The primary purpose of this investigation was to examine man's ability to tolerate positive radial accelerations ($+G_Z$ vector) as high as 3.8 g for prolonged periods of time after he had remained in the supine position 14 days. An attempt was also made to determine whether peripheral visual RT might provide an advanced warning of blackout under $+G_Z$ acceleration and to obtain extensive baseline RT data from subjects maintained in the supine position for 14 days. Such data could be useful in standardizing a centrifugation testing end point (e.g., blackout, grayout) criterion.

DESCRIPTION OF APPARATUS

A research perimeter was used to present visual stimuli to the subject at a number of locations in his visual field. This perimeter rigidly aligned the 18 individual stimuli 10° arc apart from 90° arc left to 90° arc right of the line of sight. Figure 1 shows the perimeter used in the centrifuge cab; the bedrest perimeter was identical except for stimulus luminance differences noted in table 1. Both units were comprised of support ring and test stimuli, light-sequencing control equipment, and an electronic control system.

Support Ring and Test Stimuli

The 18 individual test stimuli were rigidly aligned on a 0.61-m-radius semicircular aluminum channel. The subject's eyes were located at the center of this perimeter during the binocular testing. At each stimulus location was mounted a clear acrylic molded hemispheric plastic lens[1] 8 mm in diameter (0° 45′arc) that received light from the exit end of a 64 fiber optic bundle[2] and transmitted it as a diverging cone in the direction of the eyes. This cone of light from each lens reached a diameter of 15.2 cm at the eye location.

Light-Sequencing Control Equipment

The basic parts of the light-sequencing control equipment are illustrated schematically in figure 2. A servocontrolled light-sequencing drum was used to allow light, emitted from the fluorescent flash lamp, to enter one of the 18 fiber optic bundles in accordance with a preprogrammed presentation schedule. The primary source of light was an F8T5/CW cold cathode fluorescent flash lamp

[1]Edmunds Scientific Co., No. P-41, 232.

[2]DuPont CROFON 161OX.

driven by an Iconix model 6191-1 lamp driver. This lamp was chosen for its rapid onset rate (approximately 1μsec) and high luminance. The stimulus remained on 0.5 sec each trial. The input ends of each fiber optic bundle were aligned linearly 0.5 in. apart above the rotating "aperture" drum. Inside this drum was a fixed light shield with oval aperture to help reduce stray light. As illustrated, each fiber optic bundle had a clear acrylic molded plastic entrance lens 8 mm in diameter and 11.1 mm long (see footnote 1). This lens increased the amount of light entering each bundle approximately 10 times over the amount of light that would have entered the bundle without it.

A 28-V tungsten incandescent lamp (operated at 19 V) provided light to the 0° "fixation light" bundle.

To keep the subject from learning where the stimulus was going to appear, each of the 18 stimulus positions was presented in random order. To keep the subjects from learning when the stimulus was going to appear, six discrete inter-stimulus intervals were presented in random order. Within a block of 120 trials, 22 trials occurred after a delay of 1.8 sec, 25 trials occurred after a delay of 2.4 sec, 28 trials occurred after a delay of 2.8 sec, 22 trials occurred after a delay of 3.2 sec, 17 trials occurred after a delay of 3.6 sec, and 6 trials occurred after a delay of 4.4 sec.

Electronic Control Equipment

Figure 3 is a block diagram of the electronic control equipment.

Photometry Results

The luminance of each test stimulus is given in table 1. These values were obtained with a Pritchard Spectra photometer with standard telescopic lens and 6′ arc diameter aperture. A 9-ft-L standard source was used. These luminance levels were achieved by inserting neutral density filters at the input end of each fiber optic bundle. This particular luminance distribution from 10° arc to 90° arc on each side of the line of sight was determined in accordance with log correction factors for the large (natural) pupil data of Haines (ref. 20) and is discussed later.

TABLE 1. – PERIMETER PHOTOMETRY RESULTS[a]

Test stimulus position (deg)[b]	Centrifuge perimeter		Bedrest perimeter	
	(log c cm^{-2})	(ft-L)	(log c cm^{-2})	(ft-L)
$90°_L$	1.10×10^{-2}	32.2	6.64×10^{-3}	19.4
$80°_L$	6.44×10^{-3}	18.8	5.96×10^{-3}	17.4
$70°_L$	5.07×10^{-3}	14.8	4.69×10^{-3}	13.7
$60°_L$	3.87×10^{-3}	11.3	3.70×10^{-3}	10.8
$50°_L$	2.29×10^{-3}	6.74	2.43×10^{-3}	7.18
$40°_L$	1.78×10^{-3}	5.20	1.98×10^{-3}	5.85
$30°_L$	1.16×10^{-3}	3.42	1.40×10^{-3}	4.10
$20°_L$	4.80×10^{-4}	1.40	5.41×10^{-4}	1.58
$10°_L$	2.02×10^{-4}	.59	2.26×10^{-4}	.66
$0°$	1.20×10^{-2}	35.3	4.10×10^{-3}	12.0
$10°_R$	1.85×10^{-4}	.54	2.09×10^{-4}	.61
$20°_R$	4.18×10^{-4}	1.22	4.63×10^{-4}	1.35
$30°_R$	1.13×10^{-3}	3.35	1.16×10^{-3}	3.40
$40°_R$	1.88×10^{-3}	5.50	1.61×10^{-3}	4.73
$50°_R$	2.29×10^{-3}	6.73	2.81×10^{-3}	8.22
$60°_R$	4.18×10^{-3}	12.2	3.87×10^{-3}	11.3
$70°_R$	5.07×10^{-3}	14.8	5.14×10^{-3}	15.0
$80°_R$	6.09×10^{-3}	17.8	7.09×10^{-3}	20.7
$90°_R$	1.18×10^{-2}	34.7	1.18×10^{-2}	34.7

[a]Each value based on mean of two readings.
[b]Measured from 0° (center) fixation light position.

SUBJECTS

Eight males participated in this investigation – four were 21 years old, two were 22 years old, and two were 23 years old. Their heights ranged from 161 to 187 cm and their weights, from 61.70 to 85.30 kg. All subjects possessed 20:20 (or better) distance acuity (Snellen letters, orthorater), full and normal visual field sensitivity, and normal ocular motility. All were given at least four days of training which, from a subsequent analysis, provided for stable data thereafter.

EXPERIMENTAL DESIGN

This investigation consisted of the following experimental periods. (1) During a 3-week-long *control* period (C,1-21), the subject's total energy expenditure was measured and adjusted to equal his caloric intake. The subjects were ambulatory and under a controlled exercise and diet. (2) Next, during a 2-week-long *bedrest* period (T_1,1-14), each subject remained in the supine position at all times. The same caloric intake and outgo was used as in the control period. (3) Next followed a 2-week-long *recovery* period (R_1,1-14), during which time the subject underwent the same exercise, diet, and other conditions as in the control period. (4) A second 2-week-long *bedrest* period (T_2,1-14) followed, identical to the first bedrest period except a saline rehydration fluid was administered on day T_2,14 prior to riding the centrifuge. (5) Finally, there was a 1 week-long *recovery* period (R_2,1-7). The above abbreviations (in parentheses) will be used hereafter. During all but the last experimental periods, each subject exercised for 1/2 hr/day at about 100 W (equal to half their maximal oxygen uptake) on a bicycle ergometer. This was done in the supine position during bedrest and in the upright position during the other periods.

Each subject rode the Ames 20-g Biosatellite centrifuge on days T_1,14; R_1,14; and T_2,14 as well as several times during the control period for familiarity.

TESTING PROCEDURES

Bedrest Testing

The perimeter was positioned so that the subject's eyes were at the center of the hemispheric arc while he lay on his back. After he had adapted to total darkness for at least 5 min, a low-volume auditory tone was sounded to alert the subject for the start of the test. He held the response button in his right hand and depressed the switch with his thumb. Each peripheral test light position was presented 30 times for the 50° left to the 50° right stimulus positions and also for the 90° left and the 90° right positions. The remaining positions were presented 25 times each per test day. Five-hundred-and-ten trials were administered each test day to each subject. A total of 3570, 4080, or 4590 response times were collected per subject, depending on the number of days tested, for a total of 51,024 response times.

Each subject was tested approximately every other day during periods T_1 and T_2 and approximately every fourth day during period R_1. The bedrest graphs and data tables give the exact testing days.

Acceleration Testing

On days T_1,14 and T_2,14, the subject was carried in the supine position to the centrifuge cab, strapped on the couch, and the biomedical monitoring leads attached. The subject wore no anti-g suit and was instructed to remain muscularly passive. After the television camera was focused and the cab darkened to approximately 1.71×10^{-4} c cm^{-2} (0.5 ft-L) of dark red illumination, the 5-min-long preacceleration baseline period began. The various acceleration test periods are illustrated schematically in figure 4. The ramp-up and ramp-down rate was maintained at 0.03 g/sec. The 2-g plateau lasted 670 sec, the 3.2-g plateau lasted 220 sec, and the 3.8-g plateau lasted 185 sec (if the subject did not blackout or grayout first).

Each subject underwent each of the three g-level acceleration runs in a different (random) order. However, once a subject was assigned a particular g-level presentation order, that order was always administered to that subject to allow him to act as his own control. Response time testing was continuous until the subject blacked out, grayed out, requested to stop, or until he had completed all three acceleration runs plus the 3-min-long post-test period B_4. Periods B_2 and B_3 each lasted 5 min.

Approximately 100 RT trials were administered during the preacceleration baseline period B_1 or about 6 response times per stimulus position per subject. If he did not black out, a total of 907 response times were obtained each day or about 50 response times per stimulus position per subject. A total of 16,360 response times were obtained for all eight subjects from the centrifuge testing.

RESULTS

Bedrest Testing

The mean RT results from the bedrest portion of the study for each subject, light position, and test day are presented in figures 5 through 12. In each graph a horizontal reference line is provided for each day's data which can be used with the vertical RT measurement unit for that graph to determine mean RT for each light position. The number accompanying each curve indicates the consecutive test day within each experimental session.

Acceleration Testing

To evaluate the possibility that RT might provide an advanced indication of blackout during acceleration, individual response times were plotted for a period of about 40 sec before the run was terminated because of blackout or grayout. These data are presented in figures 13 through 36. In each figure, an open circle indicates a no response; therefore, the RT indicated for that point represents the intertrial interval. The shaded area at the right of most of the curves indicates that blackout or grayout occurred for that test. It is apparent that peripheral visual RT within approximately 40 sec of blackout does not provide a reliable advanced indicator of blackout or grayout *under these testing conditions.*

Figures 37 through 39 show the grand mean RT data for each test session, stimulus position, and centrifugation test period (preacceleration baseline, plateau g) averaged across subjects and days within sessions. All curves were fit by eye. The following observations can be made from these data.

(1) Mean RT is significantly longer (see analysis of variance results below) to stimuli imaged in the far periphery than to stimuli imaged closer to the line of sight. (2) Mean RT at each stimulus position tends to be longer at plateau g than during the preacceleration baseline period for that run by an amount δ RT that ranged from about 20 to 120 msec. (3) Mean RT tends to lengthen as g level is increased.

Tables 2 through 4 present the results of analyses of variance performed on these data. Limitations of the statistical program precluded making direct comparisons across g levels.

TABLE 2. – ANALYSIS OF VARIANCE SUMMARY FOR 2-g CENTRIFUGATION RESULTS

Source of variance	df	SS	MS	E[a]	F	p
Test session (S)	2	0.04812	0.02405	(SN)	1.847	
Stimulus position (P)	15	.1114	.0743	(NP)	8.149	<0.001
Subjects (N)	6	.6358	.1059			
(S) × (P)	30	.03557	.00118	(SNP)	1.266	
(S) × (N)	12	.1562	.1302			
(P) × (N)	90	.08208	.00091			
(S) × (P) × (N)	180	.1685	.0093			

[a]Error term.

TABLE 3. – ANALYSIS OF VARIANCE SUMMARY FOR 3.2-g CENTRIFUGATION RESULTS

Source of variance	df	SS	MS	E[a]	F
Test session (S)	2	0.06150	0.03075	(SN)	0.742
Stimulus position (P)	15	.2206	.01471	(NP)	1.731
Subjects (N)	5	.8666	.1733		
(S) × (P)	30	.2627	.00875	(SNP)	.939
(S) × (N)	10	.4146	.04146		
(P) × (N)	75	.6372	.00849		
(S) × (P) × (N)	150	.3977	.00931		

[a]Error term.

TABLE 4. – ANALYSIS OF VARIANCE SUMMARY FOR 3.8-g CENTRIFUGATION RESULTS

Source of variance	df	SS	MS	E[a]	F	p
Test session (S)	2	0.2350	0.1175	(SN)	4.053	
Stimulus position (P)	7	.3134	.0447	(NP)	6.315	<0.025
Subjects (N)	1	.0123	.0123			
(S) × (P)	14	.2268	.1620	(SNP)	.495	
(S) × (N)	2	.0579	.0289			
(P) × (N)	7	.0496	.0071			
(S) × (P) × (N)	14	.4580	.0327			

[a]Error term.

DISCUSSION

Practical Implications of the Bedrest Data

The bedrest data were collected as preacceleration baseline (control) data for comparison with each subject's centrifugation RT testing; they were not expected to change as a result of prolonged bedrest compared to previously cited RT values for the upright subject (refs. 21-28). For comparable stimulus conditions, most of the present bedrest RT data were relatively consistent within subjects across test days. This consistency was probably due to both the relatively constant response characteristics of the retina and the good stimulus repeatability.

Theoretical Implications of the Bedrest Data

There is evidence that prolonged bedrest impairs blood circulation in the head (refs. 29, 30) and that this impairment may also affect visual function. Drozdova and Nesterenko (ref. 31) observed a number of changes in visual function during their 70-day-long bedrest that may be associated with reduced cerebral blood circulation. They found a 3 mm Hg (15 percent) decrease in intraocular pressure on the 45th day of bedrest and a progressive reduction in their subject's monocular field of view. The pre-bedrest mean visual angle reported was 62.3° arc, which declined to 51° arc by the 45th day of bedrest and to 47° arc by the 67th day of bedrest. Unfortunately, no post-bedrest data are provided. Visual acuity was also found to be 21 percent lower after bedrest. The subject's mean near point of accommodation before bedrest was 8.5 cm, 12 cm on the 45th day of bedrest, and 21 cm on the 67th day of bedrest.

Drozdova and Nesterenko (ref. 31) explain their findings in terms of a disturbance to the "nutrition and oxygenation of the retinal nerve cells" that results from a "disturbance to blood circulation in the basin of the internal carotid artery. The dilation of the retinal veins indicates stagnation effects in the venous system of the retinal circulation; the dilation of the retinal arteries indicates

lowered tone of the vessels and a decrease in circulating blood mass" (ref. 31, p. 194). Other investigators have also noted these effects during prolonged bedrest (refs. 32, 33).

It is not known when the visual and intraocular changes noted by Drozdova and Nesterenko began during bedrest, however. Even if they began within the first 14 days of bedrest, it is still unlikely that the present peripheral visual RT measure would have been affected. This is primarily because of the relatively high (photopic) test stimulus luminances used. Nevertheless, it is possible that the use of very low luminance peripheral RT stimuli might be influenced by the same mechanism(s) that caused the progressive loss of peripheral visual field noted above.

The second theoretical issue has to do with the fact that, while the distribution of response times from 90° arc on the left to 90° arc on the right of the field of view was almost constant in the present investigation, most other investigators have reported significantly faster response times to photopic visual stimuli imaged upon the central retina (refs. 21-27, 34). In each of these previous investigations, however, the luminances of all peripheral stimuli were made approximately equal. There is reason to believe that the distribution of luminances used in the present investigation can account for this difference. This is discussed next.

The area-intensity reciprocity relationships of the retina have been documented rather extensively. Thus, under certain viewing situations, if the size (i.e., the retinal image area) of a visual stimulus is reduced, the same magnitude of response can still be obtained by increasing its intensity (i.e., the retinal illumination produced by the stimulus) by a certain amount. Research related to the apparent pupil (refs. 20, 35, 36) has also shown that not only the *shape* of the retinal area illuminated varies but the *area* illuminated also varies approximately as a function of the cosine of the angle between the line of sight and the line connecting the pupil with the peripheral stimulus. Therefore, to the extent that visual RT depends on both luminance (cf. refs. 19, 26, 37) and retinal image area, one might also expect RT to vary in a similar fashion. Indeed, Froeberg (ref. 38) and others have reported limited data on the area-intensity reciprocity relationship for the RT response. The present test stimulus luminances were specifically chosen to evaluate this possibility further. Thus, since the size of the test stimulus was held constant in the present investigation, the individual luminances of more peripheral stimuli (cf. table 1) were increased by a correction factor corresponding to the large (natural) pupil data reported by Haines (ref. 20). Perfect area-intensity reciprocity in the present data would have been indicated by a horizontal distribution of response times across the field of view.

Although the present bedrest RT data are remarkably constant across the subject's field of view, there is still a small amount of central depression in addition to some point-to-point variability (cf. figs. 5-12). It is probable that this slight depression represents different degrees of area-intensity reciprocity for different retinal regions. Further research should be carried out with the subject acting as his own control and a number of peripheral stimulus luminance distributions in order to test this hypothesis more fully.

Practical Implications of the Acceleration Data

On the basis of pilot study data reported by Sullivan, Vykukal, Hyatt, Haines, and Vetter (ref. 39) and a hypothetical physiological mechanism discussed by Howard (ref. 13, p. 553), we believed a peripheral RT test might provide an advanced warning of $+G_z$ induced blackout. This was not found to be the case. Nevertheless, it has been reported that if a flash of light is bright

enough, it can still be seen (and thus responded to) however deep a subject's state of blackout (ref. 13). Thus, it is possible that the present peripheral test stimuli were too bright to effectively detect loss in the blood supply to the peripheral retina under $+G_z$ acceleration. Further centrifugation studies would appear to be justified using peripheral test stimuli with luminances just above the scotopic threshold.

The initial expectation was that 14 days of bedrest would produce a number of indices of physiological deconditioning similar to those observed in the weightless environment and that this deconditioning would reduce $+G_z$ acceleration tolerance. The centrifugation data did show a significant decrease in $+G_z$ tolerance after 14 days bedrest. These data also showed that, in terms of centrifugation tolerance, the subjects had not fully recovered even after 14 days of ambulatory recovery (see ref. 40).

COMPARISON WITH OTHER RESULTS

These mean RT centrifugation results may be compared with those obtained by previous investigators where comparable stimulus parameters exist. The present 2-g grand mean RT data for the 10° and 30° arc (regardless of side of line of sight) stimulus positions are about 100 msec shorter than reported by Brown and Burke (ref. 19, cf. fig. 3) for 2-g, about 130 msec shorter for 3.2-g, and about 180 msec shorter for 3.75-g. These determinations were made by interpolating from the two stimulus luminance levels they used to the present stimulus luminances for the 10° and 30° arc stimuli. The present 3-g grand mean response times for both 10° arc stimulus positions compare very closely with the 3-g RT data reported by Kennedy, Kerr, Russell, and Franks (ref. 41) for their foveally imaged stimulus (mean RT = 350 msec), but not for their 3.5-g data (mean RT = 326 msec). The present 3.8-g grand mean RT for both 10° arc stimuli was about 360 msec. The present data appear the more reliable of the two considering the limitations of the Kennedy *et al.* study (discussed in the appendix). The present grand mean data for both 10° arc stimulus positions are about 180 msec shorter than those reported by Ruff (ref. 42) for comparable acceleration level testing conditions (i.e., 4-g plateau). This difference might be explained by differences in such parameters as luminance and size of the stimuli and by the fact that Ruff presented a choice RT test. There is a great deal of evidence to show that choice RT is significantly longer than simple RT. Finally, the present grand mean data are approximately parallel to but about 180 msec shorter (at corresponding angular separations from the line of sight) than those reported by Sullivan *et al.* (ref. 39). Nevertheless, it must be kept in mind while comparing data from different investigations that RT testing during $+G_z$ acceleration is notoriously variable both within and between subjects. The relatively large number of data points obtained per subject per condition in the present investigation should increase the reliability of these data.

Mention must also be made of the fact that the administration of saline rehydration fluid on day T_2,14 prior to riding the centrifuge did not significantly affect mean RT compared to the same conditions during period T_1,14.

The present centrifugation data also suggest that RT to the onset of visual stimuli (e.g., warning indicators, etc.) located in the far periphery of the pilot's field of view may be maintained at approximately the same duration as RT to centrally located (i.e., fixated) indicators by adjusting the

luminance of each indicator by an amount CL, where C is the cosine of the angle between the pilot's line of sight and a line connecting the pilot's eyes with the peripheral indicator and L is the luminance of the centrally located indicator.

The present centrifugation data agree with previous findings (refs. 12, 42) that once the subject notices peripheral visual symptoms such as a diffuse light fog, "redout," or dimming, it is a matter of only a few seconds before total visual failure ensues. The rapidity with which this takes place made it impossible to measure a progressive change in peripheral RT from the far periphery to the fovea during $+G_z$ acceleration.

SUMMARY

Eight males were subjected to $+G_z$ acceleration at 2, 3.2, and 3.8-g after having remained in the supine position for 14 days. Daily leg exercise was administered. The subject pressed a button as soon as he saw one of the 18 peripheral visual stimuli appear along the horizontal meridian. RT testing was continuous from 5 min before centrifugation testing began to 3 min after the last g run. RT testing was also performed approximately every other day during the bedrest portion of this study. The centrifugation results indicated that (1) mean response time was significantly longer to stimuli imaged in the far periphery than to stimuli imaged closer to the line of sight during $+G_z$ acceleration, (2) mean response time at each stimulus position tends to be longer at plateau g than during the preacceleration baseline period for that run by an amount that ranged from about 20 to 120 msec, (3) mean response time tends to lengthen as g level is increased, (4) peripheral visual response time within approximately 40 sec of blackout does not provide a reliable advanced indicator of blackout *under these testing conditions,* and (5) the subject's field of view collapsed so rapidly just before blackout that the time course of this constriction could not be measured using the present testing technique. The bedrest data showed that the distribution of response times to stimuli imaged across the subject's horizontal retinal meridian remained relatively constant from day to day during both the bedrest and recovery periods.

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APPENDIX

REVIEW OF ACCELERATION-RESPONSE TIME STUDIES

Burmeister (ref. 43) measured the foveal RT of three subjects at $+G_z$ accelerations of 3 and 4.5-g for 30 sec each. The ramp-up and ramp-down was maintained at 0.089 g/sec. A 30-sec-long pretest baseline control period preceded the ramp-up and another 30-sec-long post-test control period followed the ramp-down. The subject responded to the onset of a "small, white 4 volt bulb" by pulling back as fast as possible on an aircraft-type control stick. The stimulus was presented for 50 msec, approximately every 1.8 sec. The size and luminance of the stimulus was not specified, although Burmeister remarked that the stimulus was of "medium intensity, which stood out at once from the previous surroundings" (ref. 43, p. 278). The following grand mean response times (mean S.D. in brackets) were obtained: pretest control period = 265 (029), ramp-up = 316 (055), 3-g plateau = 334 (063), 4.5-g plateau = 329 (068), ramp-down = 306 (053), post-test control period = 279 (040) msec. Thus, RT is "prolonged at 3-g for all subjects." RT at 4.5-g is longer than at 3-g and the influence of $+G_z$ acceleration is shown more vividly by an increased standard deviation at plateau g than by an increase in mean RT.

Kennedy *et al.* (ref. 41) presented a small foveally fixated light at irregular time intervals to each of 35 subjects while they rode a centrifuge over the profile shown in figure 40. The number above each (b) plateau indicates the number of subjects who successfully reached this g level before blacking out. One subject's blackout was not accounted for.

Since each subject underwent a succession of acceleration profiles 0.5-g higher than the preceding one (until he blacked out), the cumulative effects of physiological stress and fatigue produced makes the interpretation of these data difficult. Also, because each ramp-up to reach the plateau g level was 5 sec long, a different acceleration rate occurred for each plateau condition. This factor also complicates the comparison of the results at one g level with those at another.

Table 5 summarizes the mean response times obtained during the 20-sec-long, 1.33-g "control" period (see plateau (a) in fig. 40) as well as the mean response times obtained during the 10-sec-long maximum g plateau (b) that each subject tolerated. The subjects are ordered according to their blackout g level; thus, subjects 1-3 blacked out at 3-g, subjects 4-6 at 3.5-g, etc., as indicated by column D of table 5. Column E gives the total number of acceleration profiles administered per subject. Column F gives the grand mean RT obtained during the 1.33-g control period and column G gives the grand mean (maximum g) RT for each group of subjects within each of the g levels indicated. Excessively long response times were not included in the analysis. These were arbitrarily defined as any RT greater than the mean RT plus 2.5 times the S.D. Likewise, excessively short RTs, those shorter than the mean RT minus 2.5 times the S.D., were also excluded from the analysis.

As shown in table 5, there is little difference between the "control" and maximum g mean response times. Only for those subject numbers that are starred is this difference statistically significant at or beyond the $p = 0.02$ level. Mean response times obtained during the 1.33-g period following the plateau (see (c) in fig. 40) lengthened by 18 msec ($p = 0.008$) over the 1.33-g control period mean response times.

TABLE 5. – MEAN RESPONSE TIME RESULTS OBTAINED BY KENNEDY ET AL.

(REF. 41, TABLE II)

Subject	1.33-g Control (msec)	Maximum g-level (msec)	g-Level reached	Total number of acceleration profiles	Grand mean RT	
					Col. B	Col. C
A	B	C	D	E	F	G
1	250	280	3	3		
2	330	390			323	350
3	390	380				
4	310	320	3.5	4		
5	240	270			320	326
6	410	390				
7	250	270[a]				
8	350	310	4	5		
9	320	290				
10	350	340				
11	530	510				
12	300	320				
13	260	230			320	315
14	240	250				
15	300	280				
16	330	340				
17	310	350				
18	300	280				
19	260	280				
20	370	350	4.5	6		
21	390	440			360	383
22	320	360				
23	300	270	4.5	6		
24	330	340			376	333
25	500	510				
26	310	330	5	7		
27	330	300				
28	300	330				
29	340	350			315	320

[a]The original report did not indicate to which g-level group this S belonged.

TABLE 5. – MEAN RESPONSE TIME RESULTS OBTAINED BY KENNEDY ET AL.

(REF. 41, TABLE II) – Concluded

Subject	1.33-g Control (msec)	Maximum g-level (msec)	g-Level reached	Total number of acceleration profiles	Grand mean RT	
					Col. B	Col. C
A	B	C	D	E	F	G
30	270	270				
31	340	340				
32	570	510	5.5	8		
33	350	330	6	9		
34	340	320	6.5	10		
35	280	270	8	13		
Grand Mean	333	334			335	344

An analysis of the relation between RT and visual symptomology during positive acceleration by Kennedy *et al.* (ref. 41) indicated that mean RT increases significantly (42 msec, $p < 0.001$) in those runs that produced either blackout or unconsciousness. In contrast, mean RT was shorter at plateau than during the control period in those runs that produced no visual symptoms. The authors remark that "This probably does not mean that runs which produce blackout or unconsciousness result in an increase in reaction time as another symptom. It seems more likely that the extra time taken was a direct result of visual failure" (ref. 41, p. 214).

Canfield, Comrey, and Wilson (ref. 44) measured thumb-pressing RT to the onset of a small (1° 35′ arc diam.) incandescent lamp with frosted lens and to a buzzer. Only the results for the visual stimulus are reviewed. Each of the sixteen subjects was given a few indoctrination rides at 2-, 3-, 4-, and 5-g acceleration ($+G_z$ vector) while wearing the Navy Coverall Anti-G Suit, Type Z-2. Then 6 acceleration runs were each administered twice in random order each day on each of 4 test days. The levels tested were 1, 3 and 5-g. During each maximum g plateau, the visual stimulus was presented irregularly 1 to 3 sec apart for a total of 5 responses. Only the total cumulative RT for these 5 responses was recorded. Thus, a total of only 24 cumulative response times was obtained per subject per entire experiment. Table 6 presents the major results from this investigation.

Mean RT was found to increase significantly ($p < 0.01$) as the g level increased above the 1-g "control" condition. These response times were not obtained from any subjects who experienced either grayout or blackout. The investigators point out: "This does not guarantee that the change

TABLE 6. – RESULTS OBTAINED BY CANFIELD ET AL. (REF. 44, TABLE 1)

	Positive acceleration level (g)		
	1 (control)	3	5
Mean RT	1.229	1.289	1.327
S. D.	.107	.125	.106
$S.E._{\bar{x}}$	.028	.032	.027

can be attributed to factors involving the central nervous system, of course. It is a definite possibility that the striking changes in visual performance that are called "gray-out" and "black-out" are only arbitrary points on a continuum of decreasing retinal function." They also remark that, "Increased radial acceleration seems to produce a definitely slower reaction time where the time required to complete the reaction movement itself is negligible, as it was in this study. The increase in time can be attributed to either a reduced sensory efficiency, a decreased efficiency of the central nervous system, or a combination of the two" (ref. 44, p. 354).

Comrey, Canfield, Wilson, and Zimmerman (ref. 45) quantified perceptual scanning speed by presenting sets of small black and white photographs each containing five similar figures. One "prototype" figure was in the middle and the other four situated above, below, to the right, and to the left of it. Three of the four surrounding figures were slightly different and one was identical to the "prototype" figure. The subject's task was to call out the position of the identical figure. A series of such stimuli was presented for 15 sec during the maximum g plateau portion of each acceleration profile. All subjects wore the Navy Coverall Anti-G Suit, Type Z-2, inflated to a point between 1.5 and 2.3-g. Each of the 14 subjects was given 6 rides on each of 3 test days. On each test day, two experimental runs were administered at $+G_Z$ levels of 1, 2.5, and 4-g. A 3-g ride was given to each subject before the experimental rides each day to accustom him to the centrifuge situation.

The results comprise the number of correct figure detections made at each g level. Table 7 summarizes the statistical results obtained. The subject's perceptual speed scores were significantly lower for the 4-g condition than for the 1- or 2.5-g levels during the first three conditions each day compared to the last three. The investigators suggest that this "strongly suggests that the g forces imposed functioned largely as a distracting influence to which the subjects readily adapted as the day's experimental trials progressed" (ref. 45, p. 64).

TABLE 7. – RESULTS OBTAINED BY COMREY ET AL. (REF. 45)

		Positive acceleration level (g) comparisons		
		1 vs. 2.5	2.5 vs. 4	1 vs. 4
First three trials	t Ratio	0.16	2.81[a]	4.07[a]
	correlation	.43	.32	.62
Last three trials	t Ratio	.28	.74	.96
	correlation	.85	.71	.57

[a]Significant at $p < 0.01$ level.

These findings suggest that the basic physiological changes that occurred were not responsible for the decrement in performance at the higher g levels during the first three trials and, so far as the ability of the visual system to discern visual detail and respond rapidly during increased positive radial acceleration is concerned, little effect was found.

Canfield *et al.* (ref. 44) raise an important question regarding the mechanism that underlies lengthened RT as a function of increased

$+G_z$ acceleration, namely, that if the effect of increased g is great enough to reduce the sensitivity of the retina to the point where the test light loses much of its perceived brightness, then the change in RT could be the result of the same factors apparently involved in lengthened RT with less intense stimuli. If this were the case, the phenomenon could be ascribed to retinal (i.e., peripheral) rather than central processes. If this hypothesis is correct it would suggest that by increasing the intensity of the light, the relative amount of RT change would decrease as the acceleration level increased. This possibility was evaluated in the next investigation reviewed.

Brown and Burke (ref. 19) measured visual RT to the onset of small (29 ′arc diam.), diffuse white, tungsten filament stimuli presented at each of two luminances (4560 and 0.025 ml). These test lights were located at two positions in the subject's monocular visual field: 7° 24′arc and 28° 22′arc to the nasal side of the fixation position. The intertrial interval ranged from 1 to 4 sec. After from 5 to 10 min of adaptation to the darkened environment, a set of three standardization $+G_z$ acceleration runs was given (profiles a, b, c, in fig. 41), followed by the experimental (test) runs. Five- to 10-min-long rest periods separated each acceleration profile. RT testing began 15 sec before each ramp-up began and ended 5 (or more) sec after the profile was completed. The subject was instructed to remain muscularly passive throughout all the test runs. The criterion of visual impairment used was the subject's failure to respond to a visual stimulus within 1.5 sec after its onset.

Two separate series of acceleration profiles were given to each subject each test day. In the first, the g level at plateau was increased by 0.3 g on each succeeding run until the response criterion was reached. In the second series, the first plateau administered was 0.9 g lower than the g level at which the subject reached the response criterion or at 3 g, whichever was higher. However, no attempt was made to see whether peripheral vision returned after several seconds.

The primary RT results are presented in table 8 and may be summarized as follows: (1) All analyses involving test light luminance as a main effect were statistically significant. (2) Test light location within the visual field was not significantly related to RT at any level when response times longer than 1.5 sec were excluded. (3) No significant relation was found between mean RT and

TABLE 8. – INTERPOLATED MEAN RESPONSE TIME RESULTS[a] OBTAINED BY BROWN AND BURKE (REF. 19, FIG. 3).

Subject	Test light luminance (ml)	Acceleration level (g)			
		1 (control)	2–2.6	2.9–3.4	3.5–4.0
1	0.025	480	520	530	555
	4560	340	335	370	420
2	0.025	435	465	550	640
	4560	320	325	380	405

[a]All values in msec.

acceleration level until the second 5 sec at maximum plateau g was reached. (4) No significant differences were noted between response times measured during runs in which no subjective symptoms were observed and runs in which the subjects reported visual effects. (5) It is impossible to conclude that the variations in RT under increased positive acceleration are localized in the eye rather than in the brain. (6) One's g tolerance may be "raised" by either increasing the luminance of the test light and/or by positioning it closer to the line of sight (i.e., imaging it closer to the center of the fovea). (7) The effect of acceleration on the visual system was most likely not a direct mechanical one because RT did not show a prolongation during the first 5 sec at plateau whereas it did during the last 5 sec at plateau.

Frankenhaeuser (ref. 46) measured choice RT of seven subjects at a $+G_z$ acceleration of 3-g. The ramp-up was maintained at 0.375 g/sec. A 120-sec-long pretest control period preceded the ramp-down and another post-test control period followed the ramp-down. Each plateau lasted 4 min and the RT data were analyzed for the first and second 2-min-long period at plateau. Each of the three 0.5-W stimulus lamps subtended 41'arc diam. at 1 m distance. The green stimulus was situated 3° 10'arc above and the white stimulus 3° 10'arc to the left of the red stimulus. These three stimuli were presented in random order approximately every 2 sec. The subject held a response switch in each hand and was instructed to press the right-hand switch if the green stimulus appeared alone or if the red and white stimuli appeared simultaneously. He was to press the left-hand switch if the red stimulus appeared alone or if the green and white stimuli appeared simultaneously. He was not to respond if the red and green stimuli appeared simultaneously. This five-choice response produced a 20-percent guessing factor.

The following grand mean response times and mean S.D. (in brackets) were obtained: pretest control period = 724 (184); first 2 min at $+G_z$ plateau = 782 (231); second 2 min at plateau = 750 (214); post-test control period = 729 (190) msec. A test performed on these data showed that the grand mean pretest control RT differed from the grand mean RT for the first 2 min at $+G_z$ plateau at the $p < 0.05$ level. The effect of $+G_z$ acceleration on choice RT was "more pronounced during the first two minutes than during the last two minutes" at maximum g.

Ruff (ref. 42) conducted an extensive series of investigations at the Institute for Flight Medicine in Germany. He quantified choice RT during various $+G_z$ acceleration profiles and during control periods to see if RT could be used to predict blackout. The subject's task was to respond as fast as possible to one of six visual stimuli (no other details given) presented 10 times per minute. In all cases the ramp-up slope was constant at 0.013 g/sec, which required approximately 4.8 min to reach the maximum acceleration of 4.5-g. The plateau g level was maintained either until the subject blacked out or for about 3.2 min. Each subject was given a 20-min-long RT test practice session followed by a 10-min-long control period during which time the subject took the RT test without any centrifuge motion. This was followed by a ride on the centrifuge with no RT testing. Acceleration and RT testing followed.

The results of Ruff's investigations may be summarized as follows. (1) Only about 1 percent of the subjects (from a sample of more than 200) showed significant changes in RT as a function of increased acceleration before grayout or blackout occurred. (2) Most subject's response times were about 410 msec long during the preacceleration resting baseline period and about 550 msec long at a 4-g plateau (cf. ref. 42, fig. 10). (3) Increased acceleration or prolonged exposure to a sufficiently high constant acceleration level did not generally impair response efficiency, as is found under oxygen deficiency. (4) Blackout occurred unexpectedly.

Sullivan *et al.* (ref. 39) reported an investigation conducted at Ames Research Center, the primary objective of which was to determine what effect hypohydration might have on both RT and $+G_z$ acceleration tolerance. Each of three subjects pressed a button as soon as they perceived one of twelve 30 'arc diameter, 35-ft-L luminance red test lights come on. These lights were located 10° arc apart and were imaged along the subject's horizontal retinal meridian from 40° to 90° arc on the right- and left-hand sides of the line of sight. The subject voluntarily fixated a small (25' arc diameter), 11-ft-L luminance white cross. Each test stimulus was automatically turned on for 0.75 sec at random intertrial intervals that ranged from 1.9 to 7.5 sec (mean of 4 sec). These 12 stimuli were presented in random order to preclude learning effects.

The acceleration profile for each subject is shown in figure 4. The three plateau g levels were 2, 3, and 3.5 and the ramp-up and ramp-down were constant at 0.066 g/sec. Each subject received a different g level presentation order.

The results may be summarized as follows. (1) During the control acceleration runs, before the subject was hypohydrated, peripheral visual RT averaged about 550 msec but during the hypohydrated acceleration runs, RT not only became more variable but also tended to lengthen for those test lights located at or near the periphery of the subject's visual field. (2) Time to blackout was significantly reduced under the hypohydrated condition for the 3 and the 3.5-g runs. (3) RT tended to lengthen prior to grayout or blackout for two of the subjects by as much as 200 msec without their realizing it. This finding must be considered tentative, however, considering the small number of subjects tested and the relatively slow data-sampling rate. Portions of the present investigation may be considered to be a replication of this earlier investigation.

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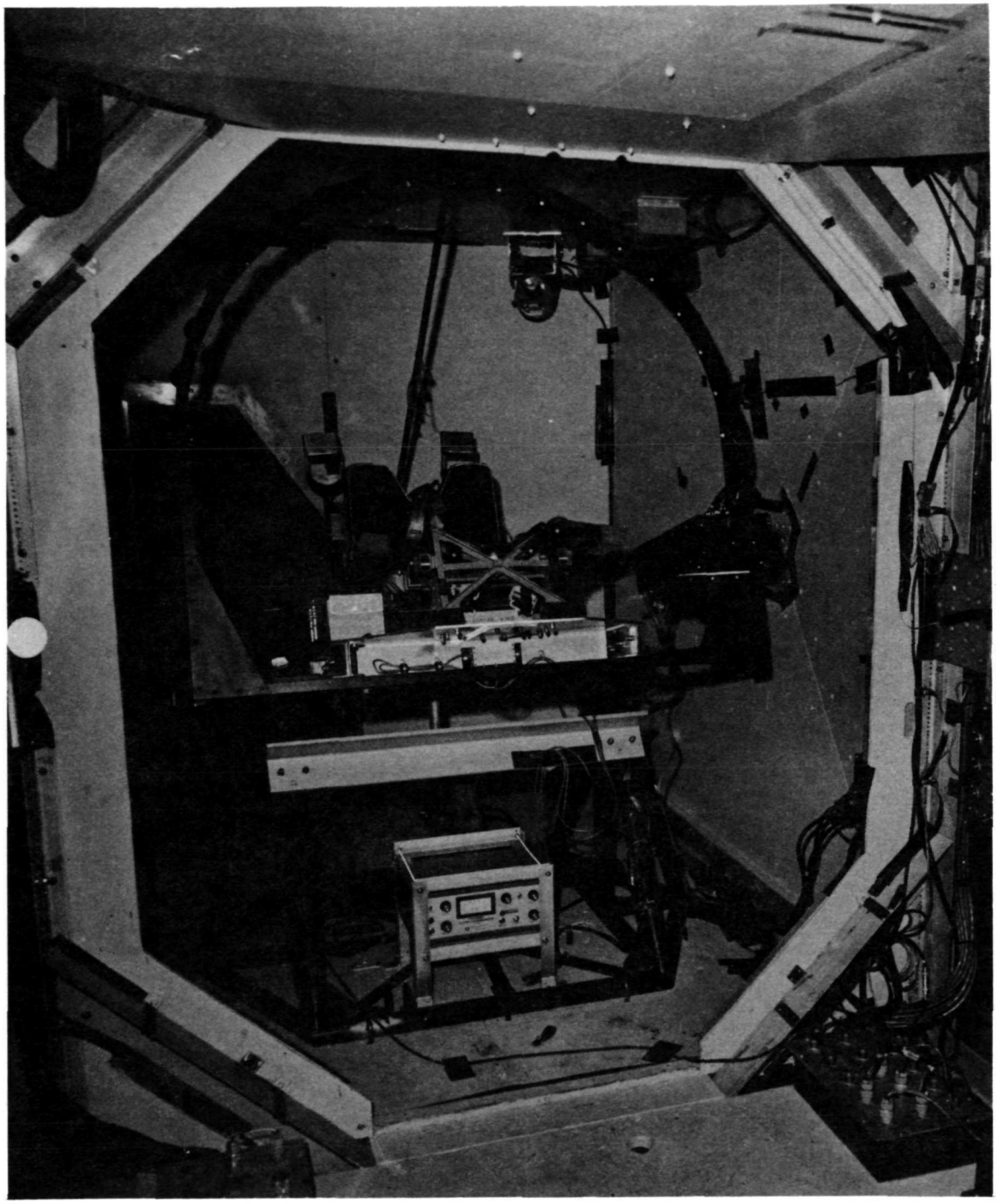

Figure 1. – Photograph of centrifuge response time perimeter.

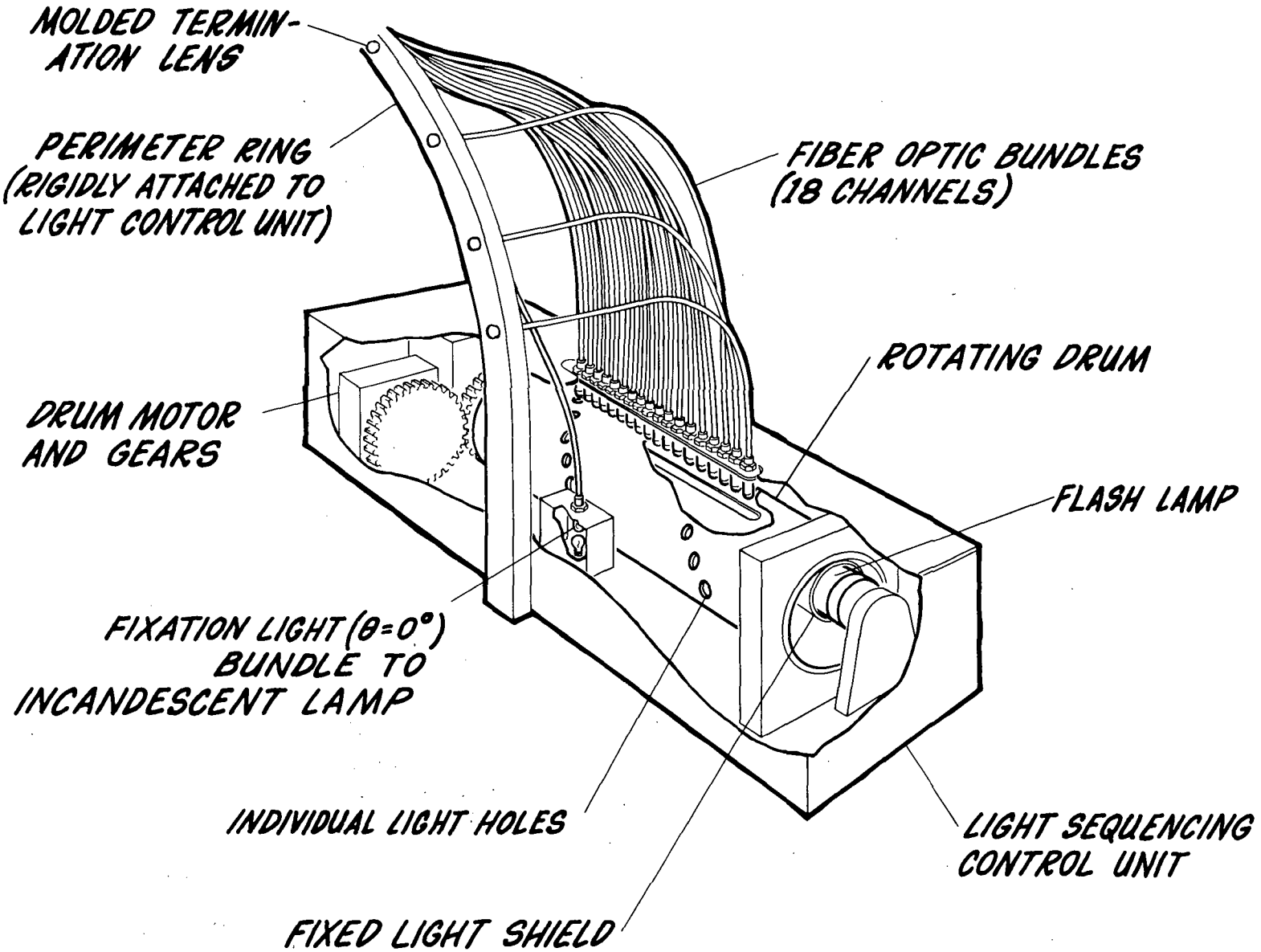

Figure 2. – Schematic diagram of light sequencing control equipment.

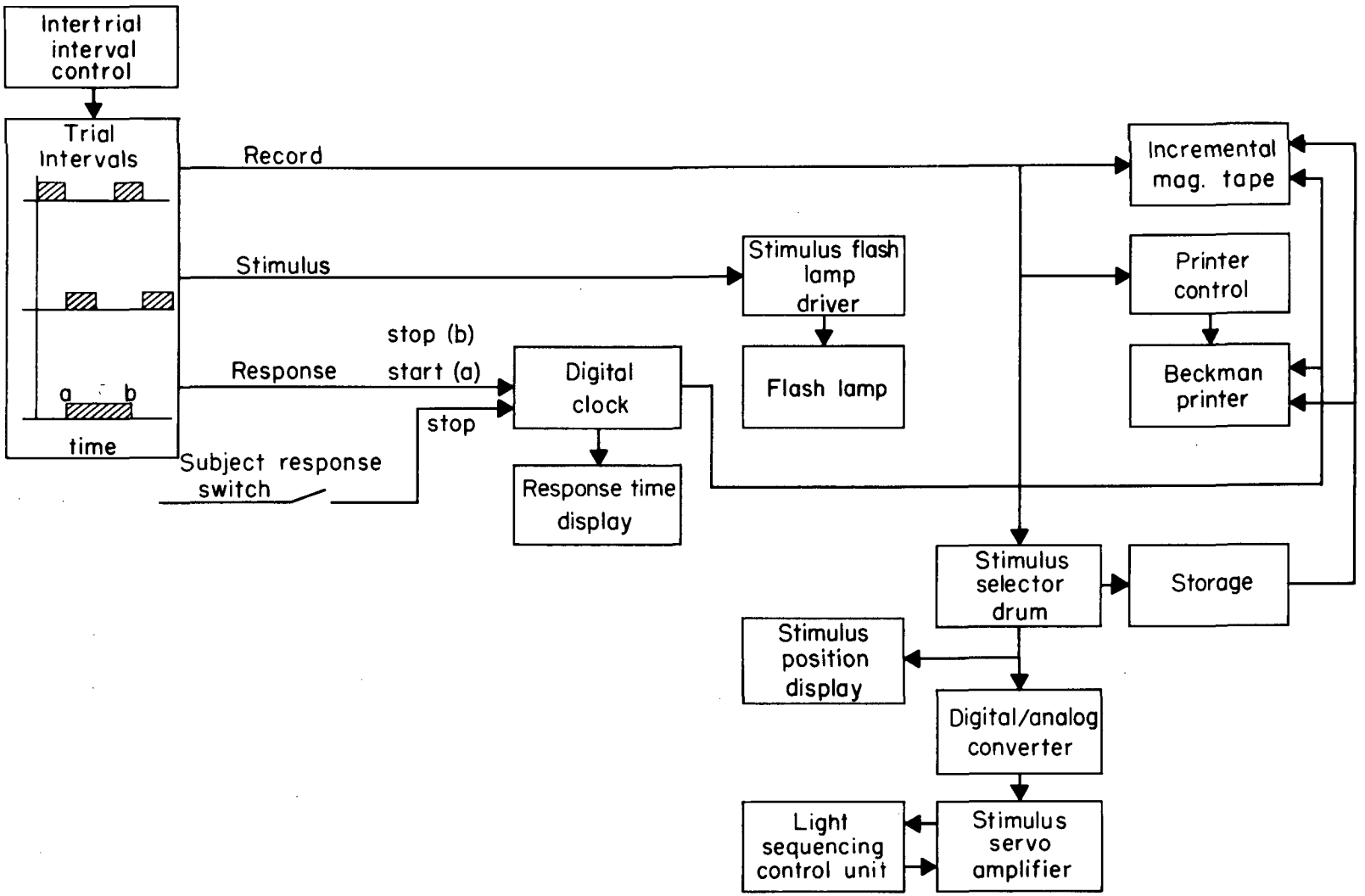

Figure 3. – Block diagram of electronic control equipment.

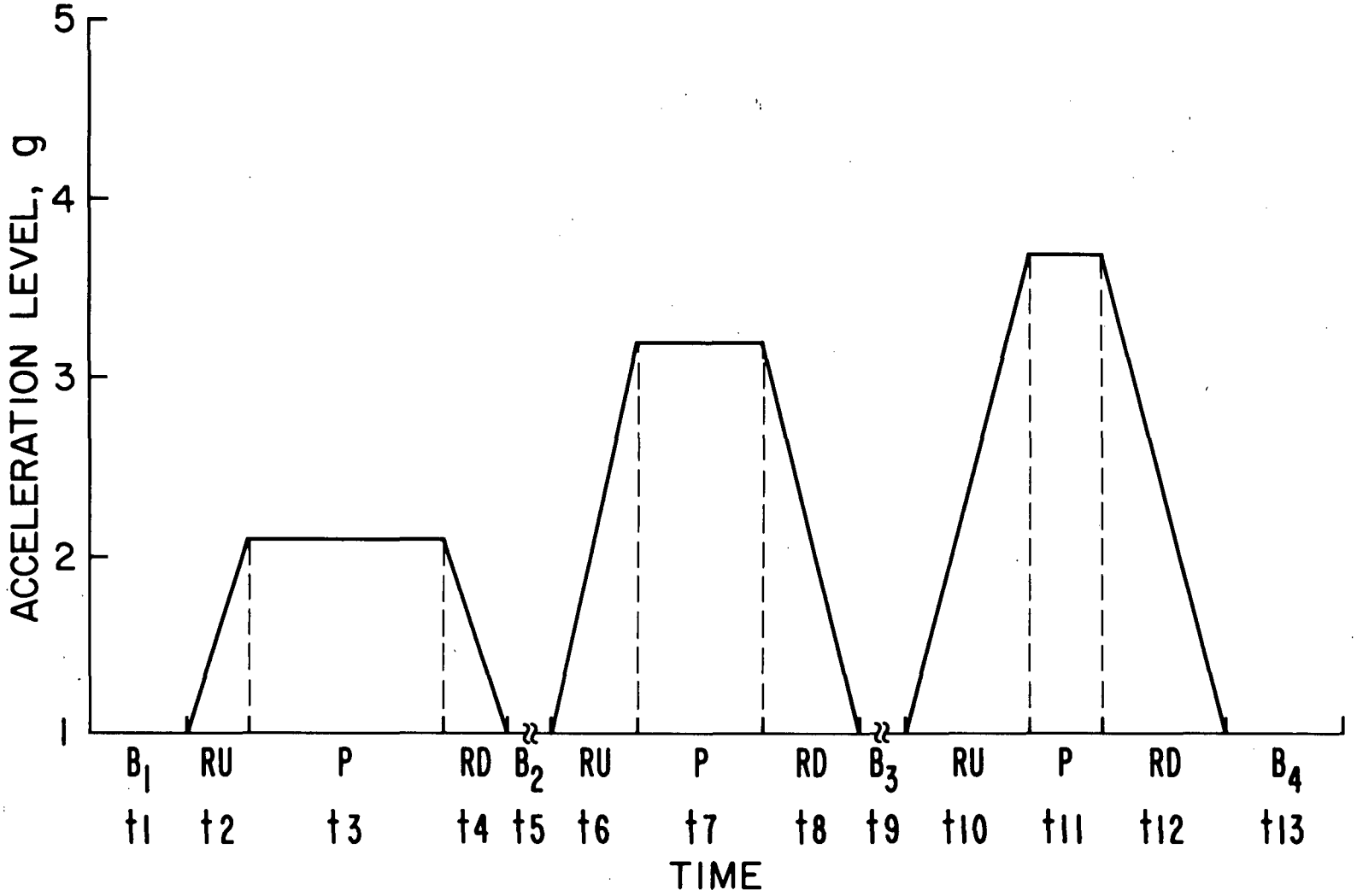

Figure 4. – Acceleration profile administered.

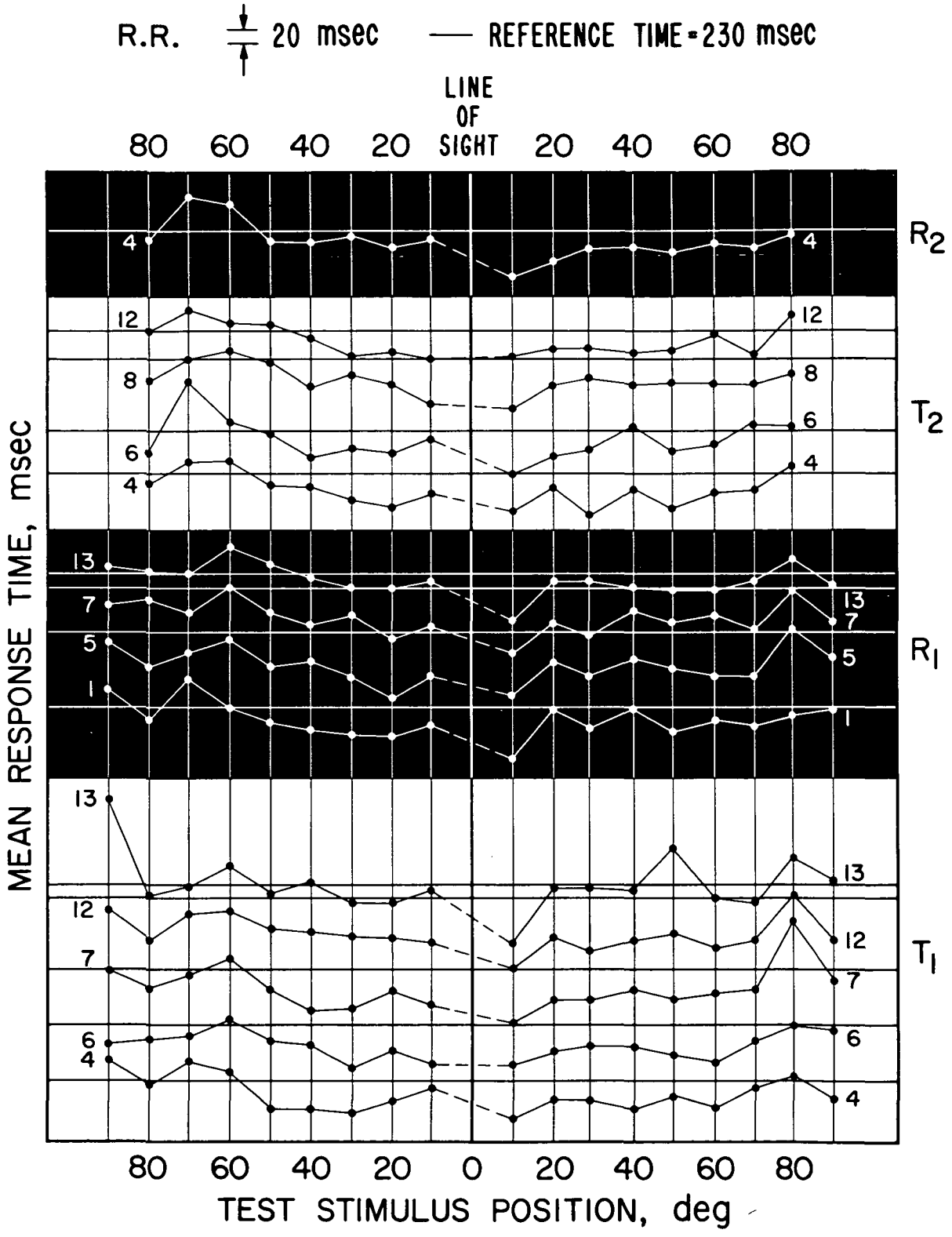

Figure 5. – Bedrest mean response time results for subject RR.

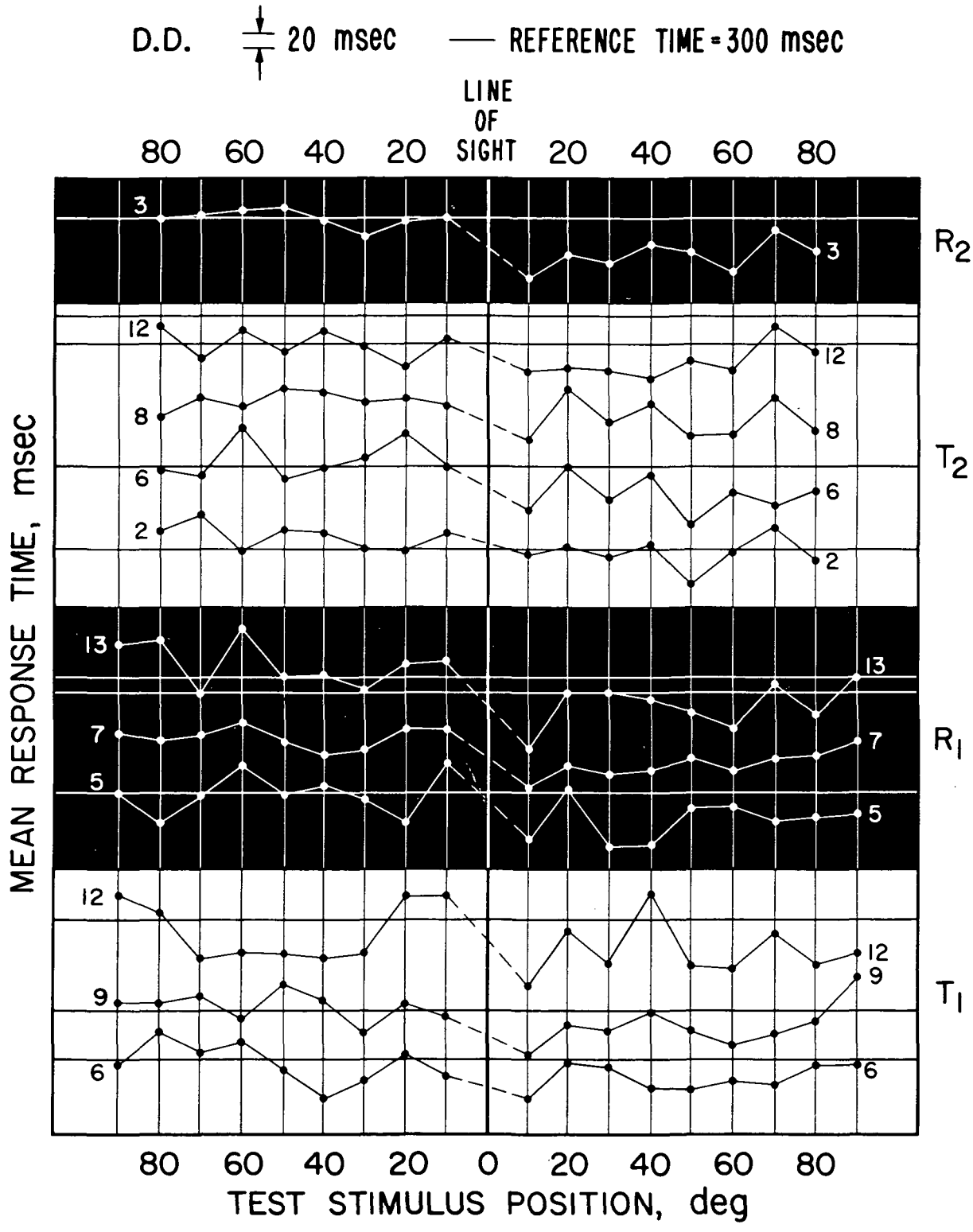

Figure 6. – Bedrest mean response time results for subject DD.

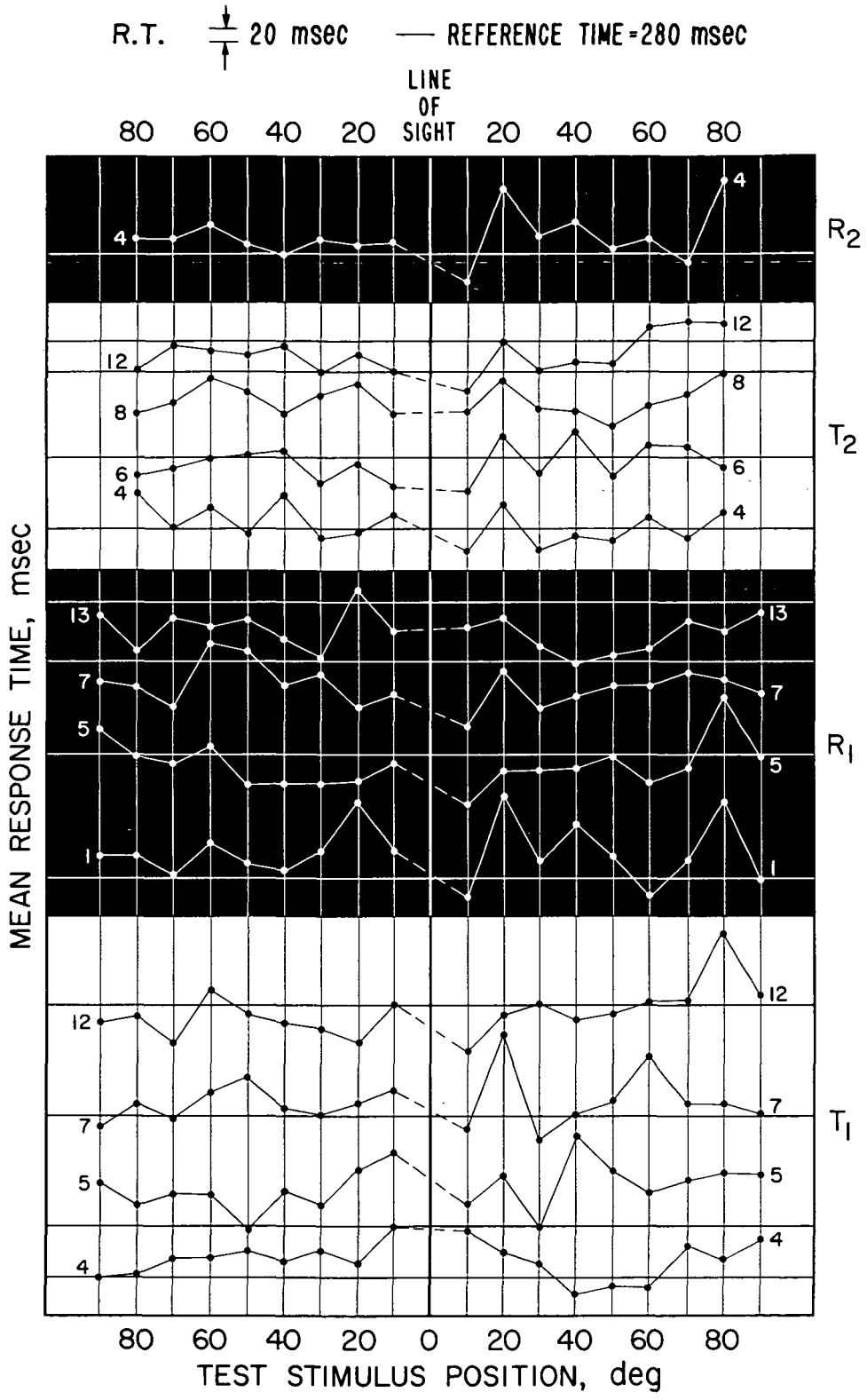

Figure 7. – Bedrest mean response time results for subject RT.

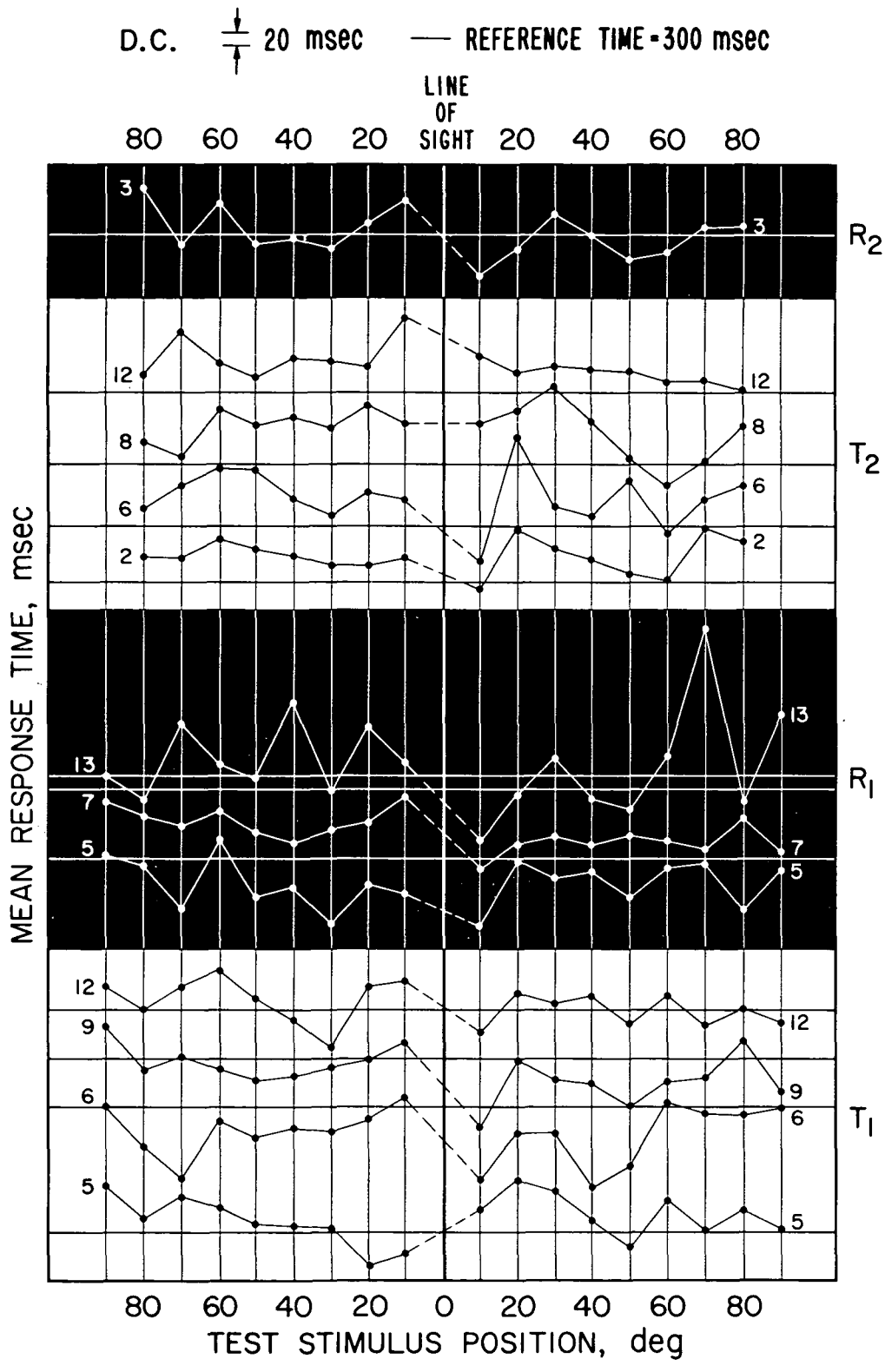

Figure 8. – Bedrest mean response time results for subject DC.

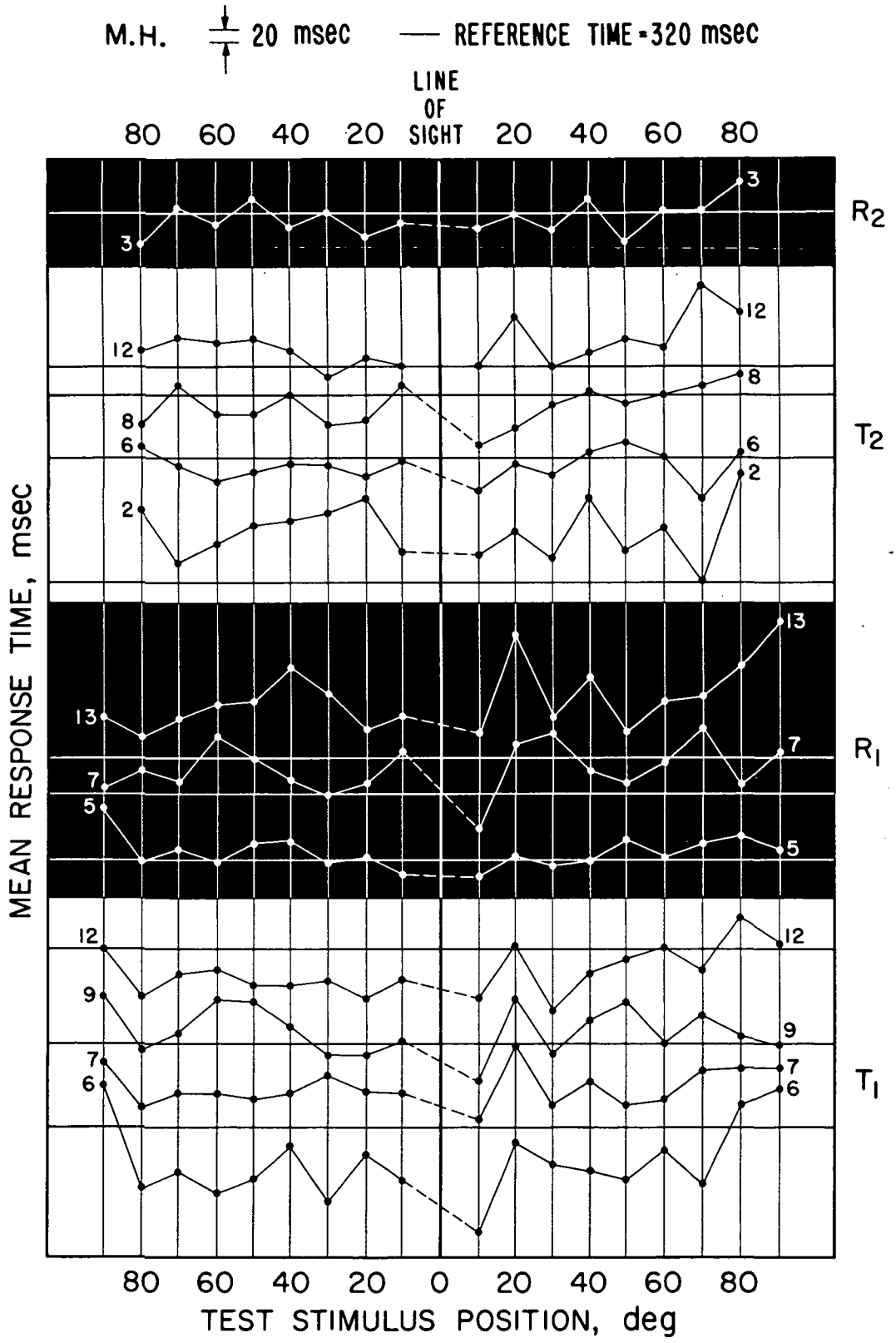

Figure 9. – Bedrest mean response time results for subject MH.

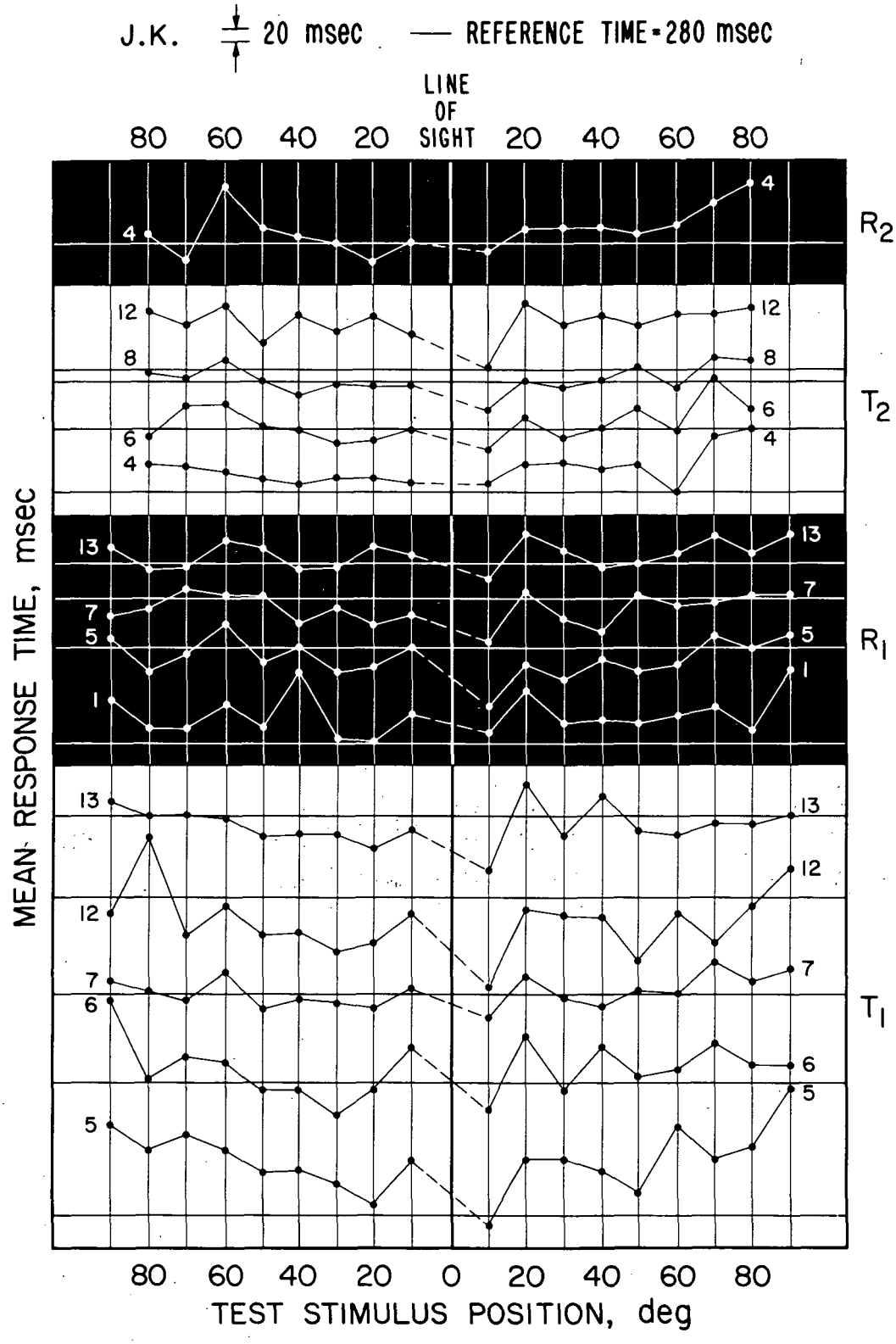

Figure 10. – Bedrest mean response time results for subject JK.

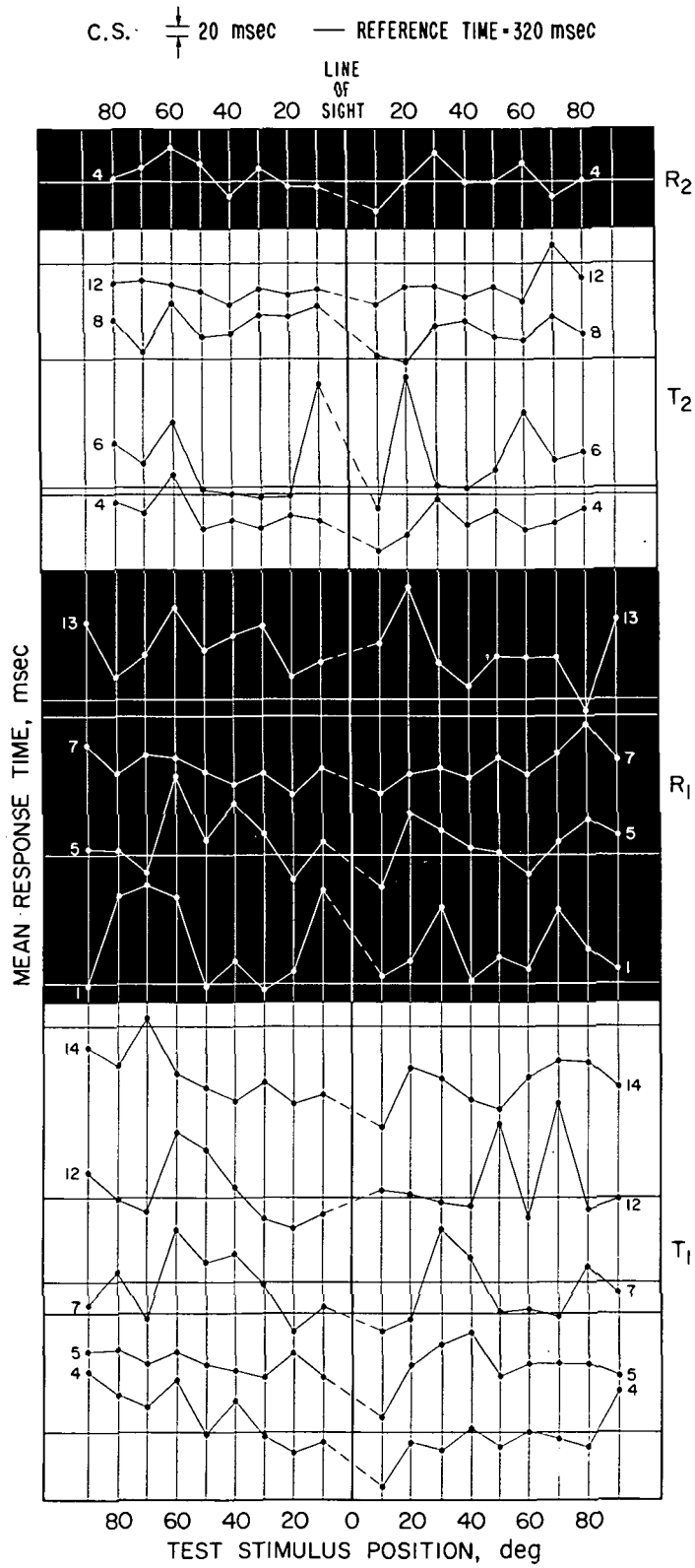

Figure 11. – Bedrest mean response time results for subject CS.

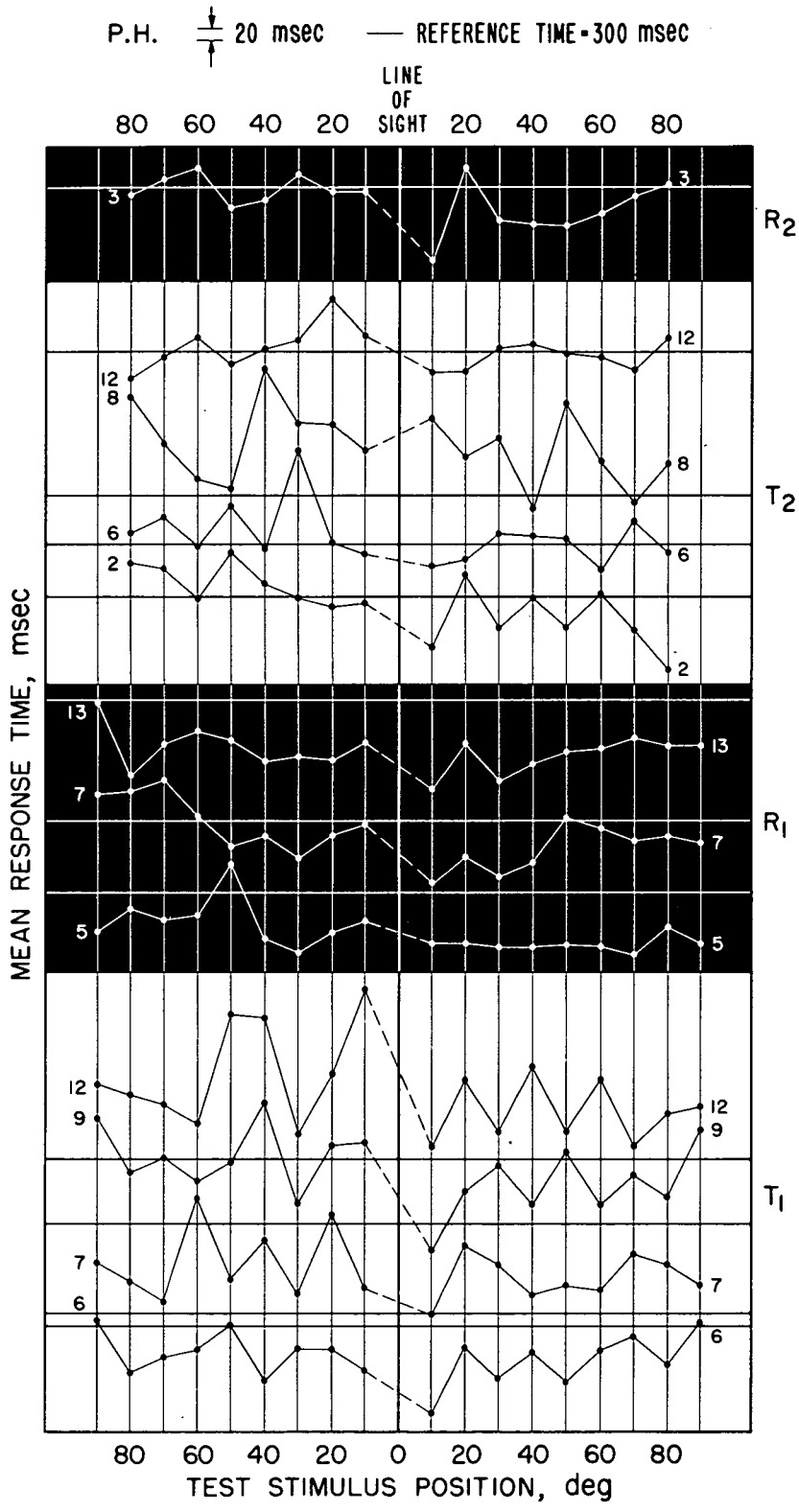

Figure 12. – Bedrest mean response time results for subject PH.

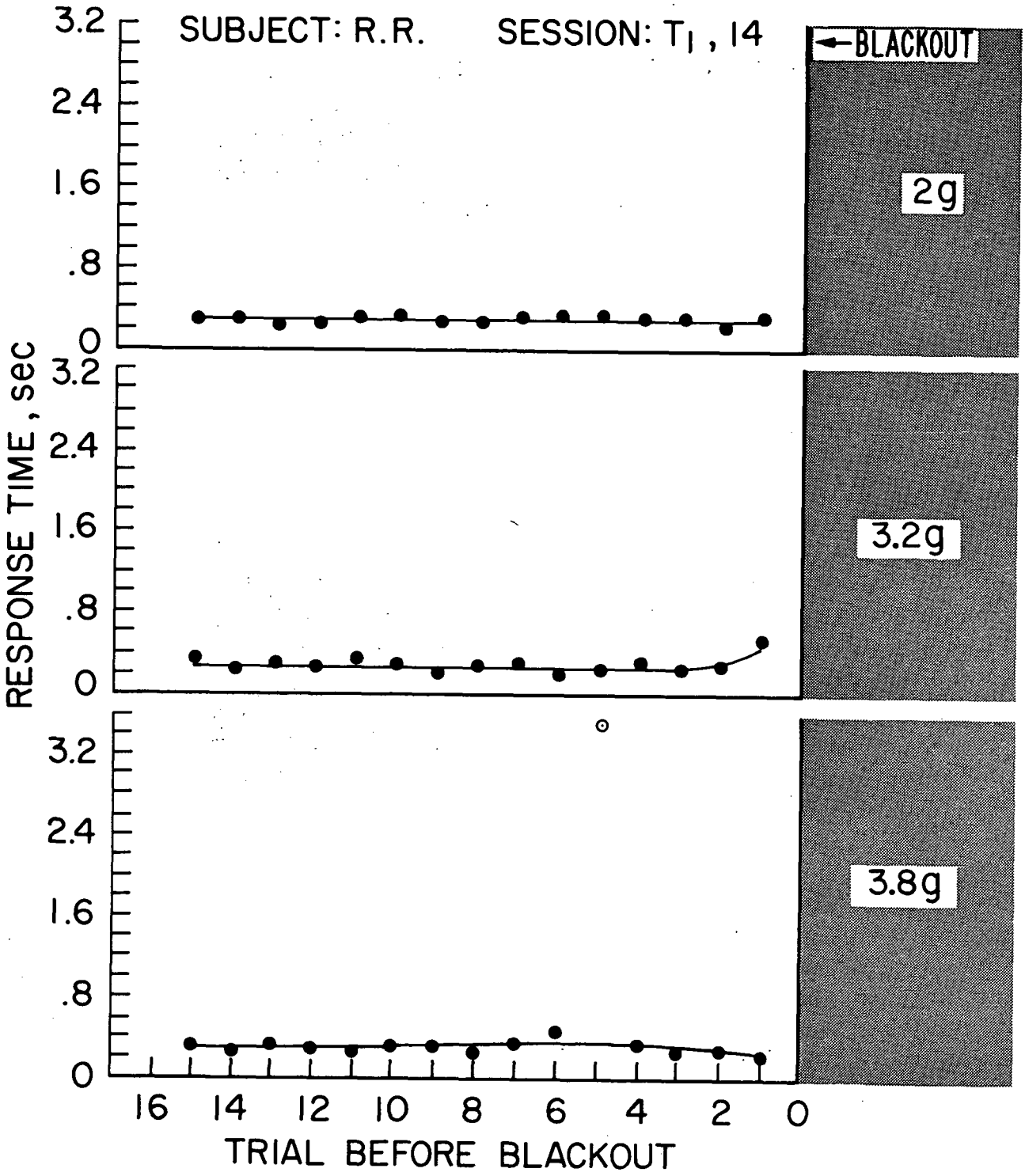

Figure 13. – Trial by trial response times prior to blackout for subject RR, session T_1,14.

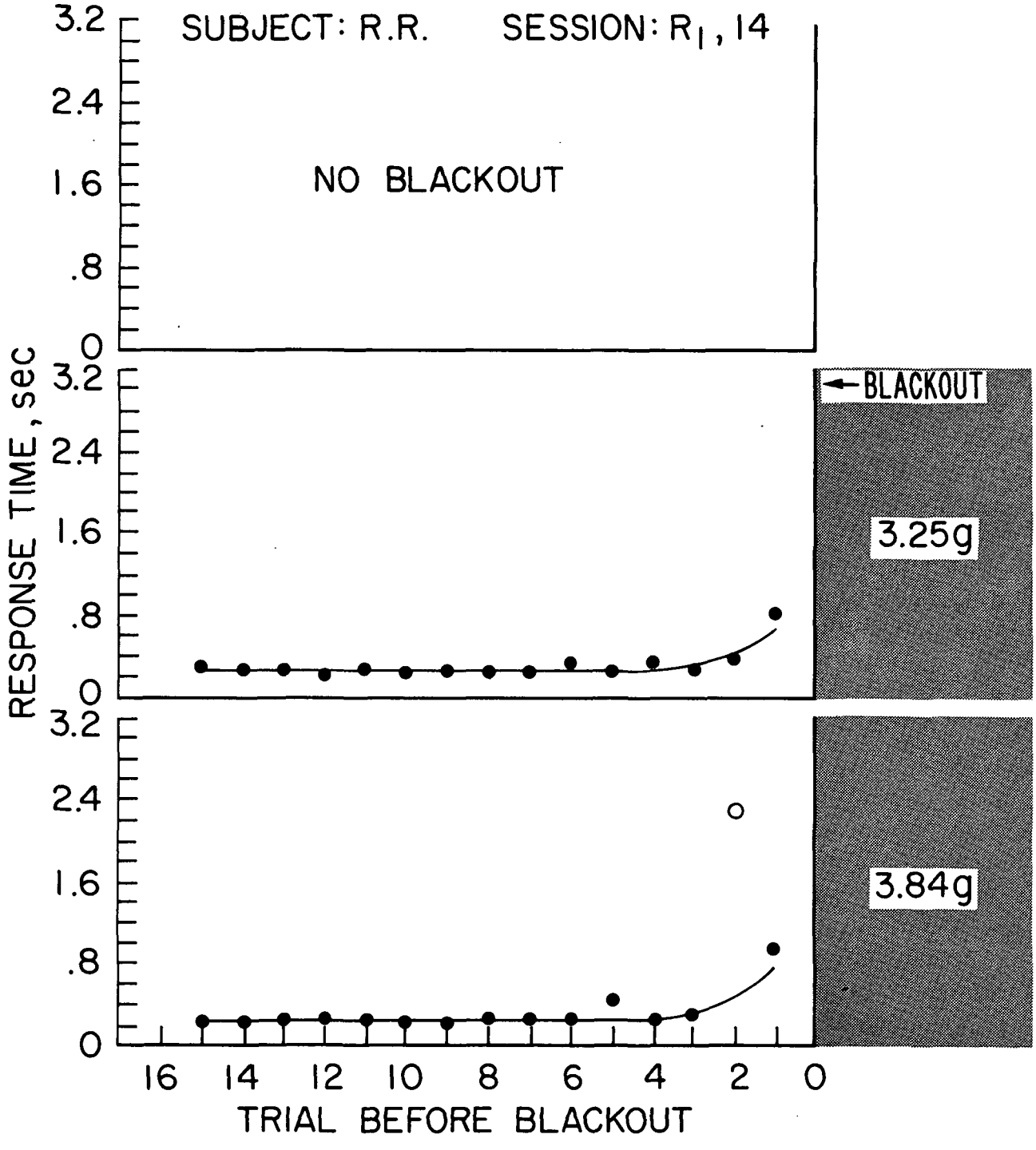

Figure 14. – Trial by trial response times prior to blackout for subject RR, session R_1,14.

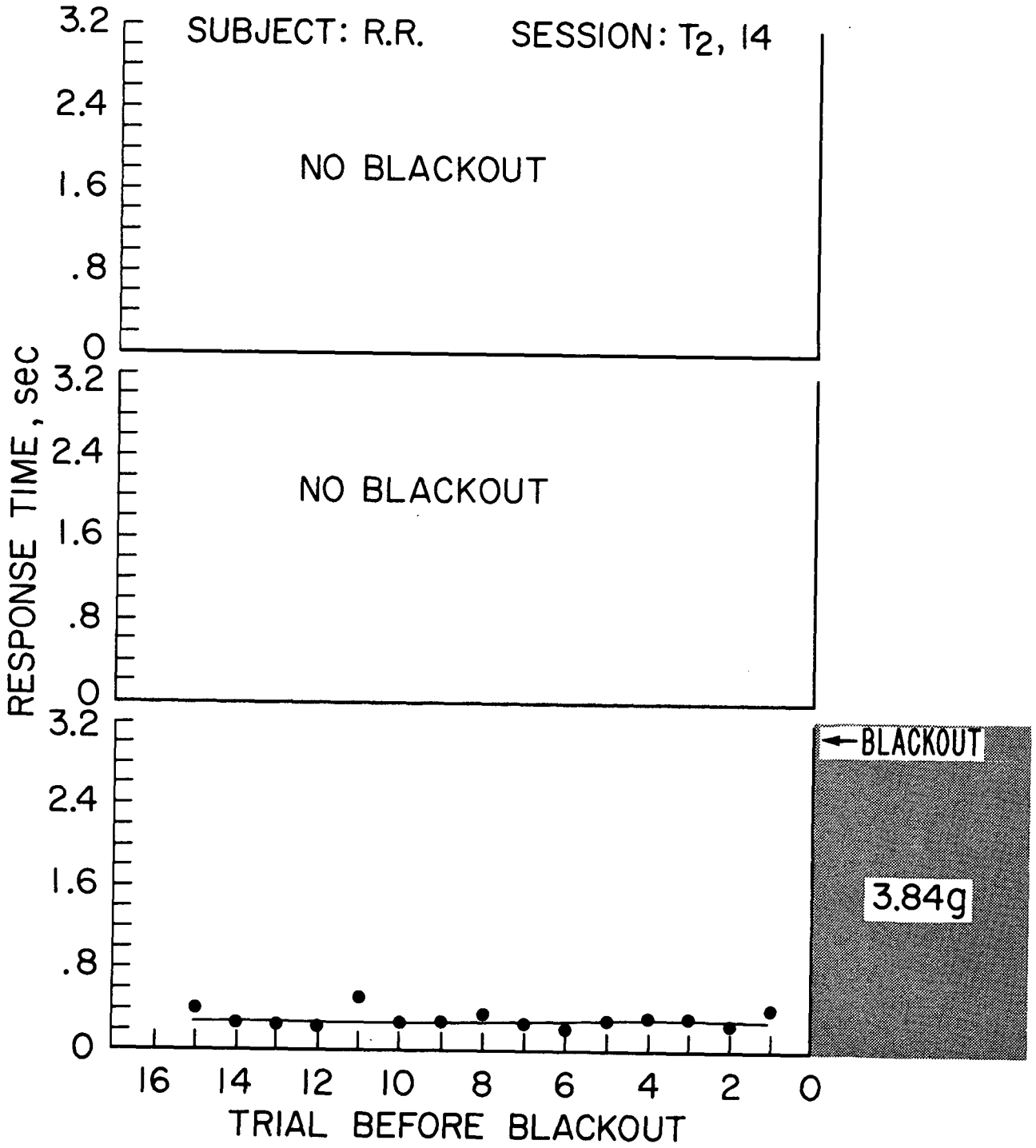

Figure 15. – Trial by trial response times prior to blackout for subject RR, session T_2,14.

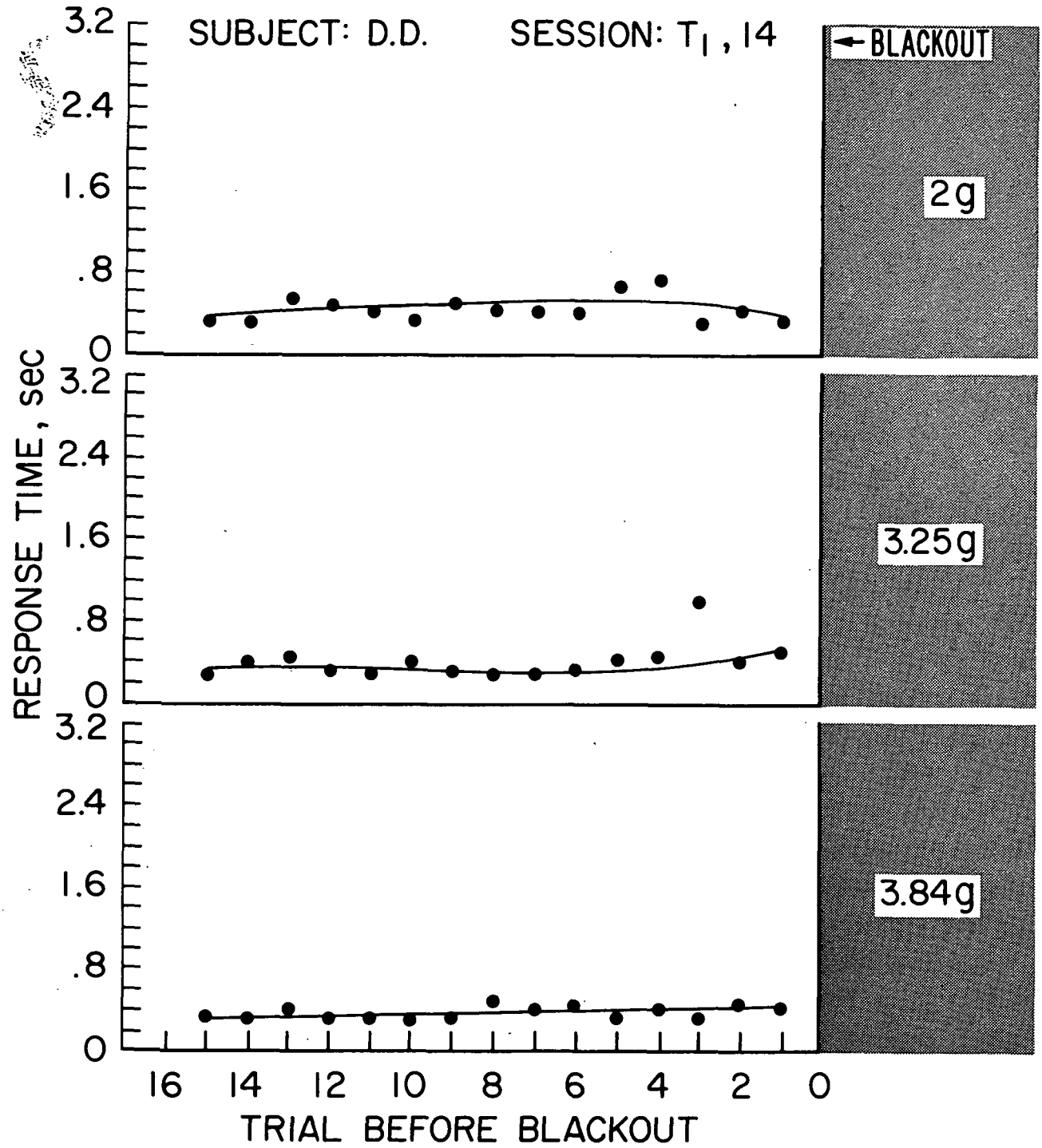

Figure 16. – Trial by trial response times prior to blackout for subject DD, session T_1,14.

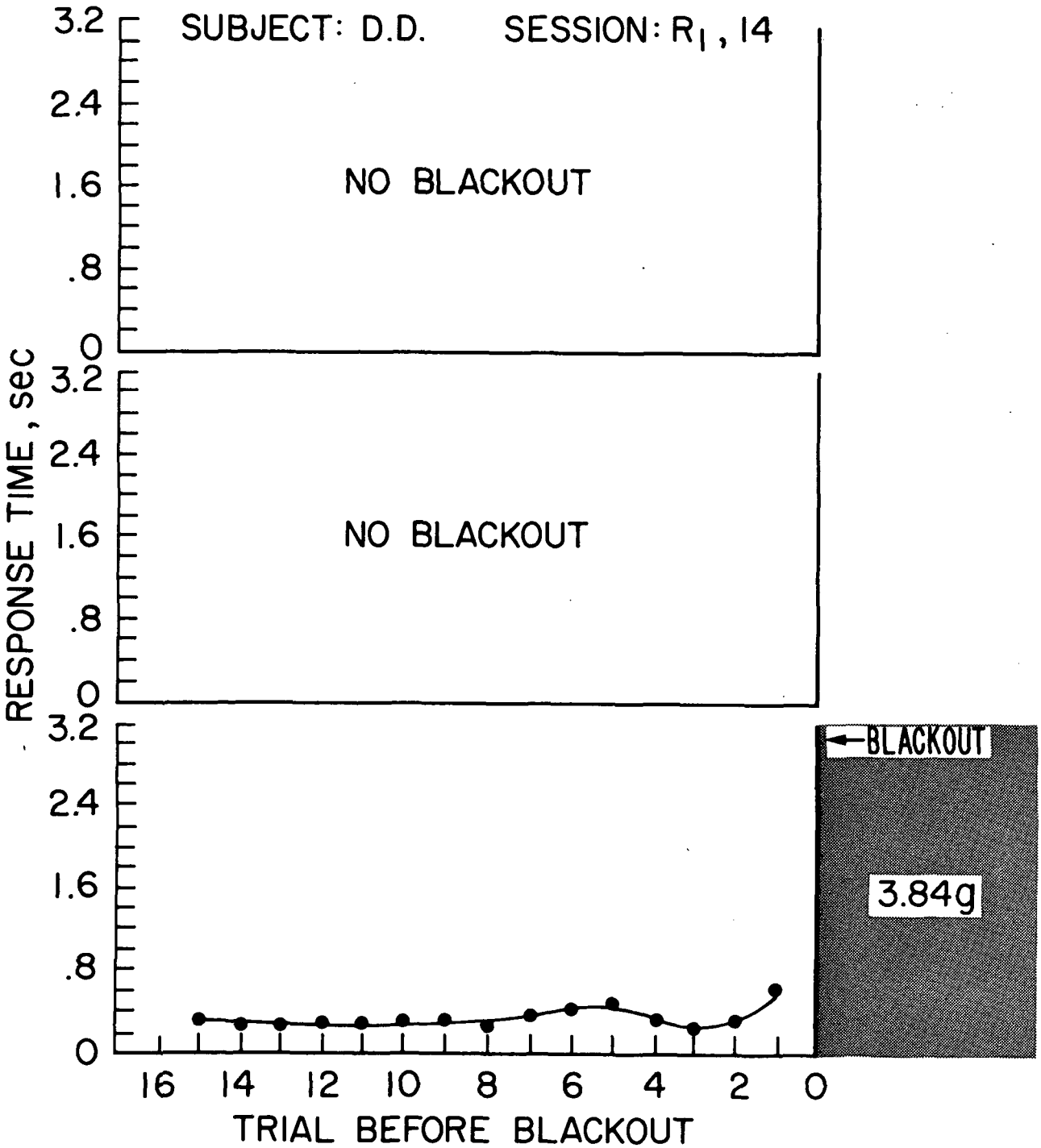

Figure 17. – Trial by trial response times prior to blackout for subject DD, session R_1,14.

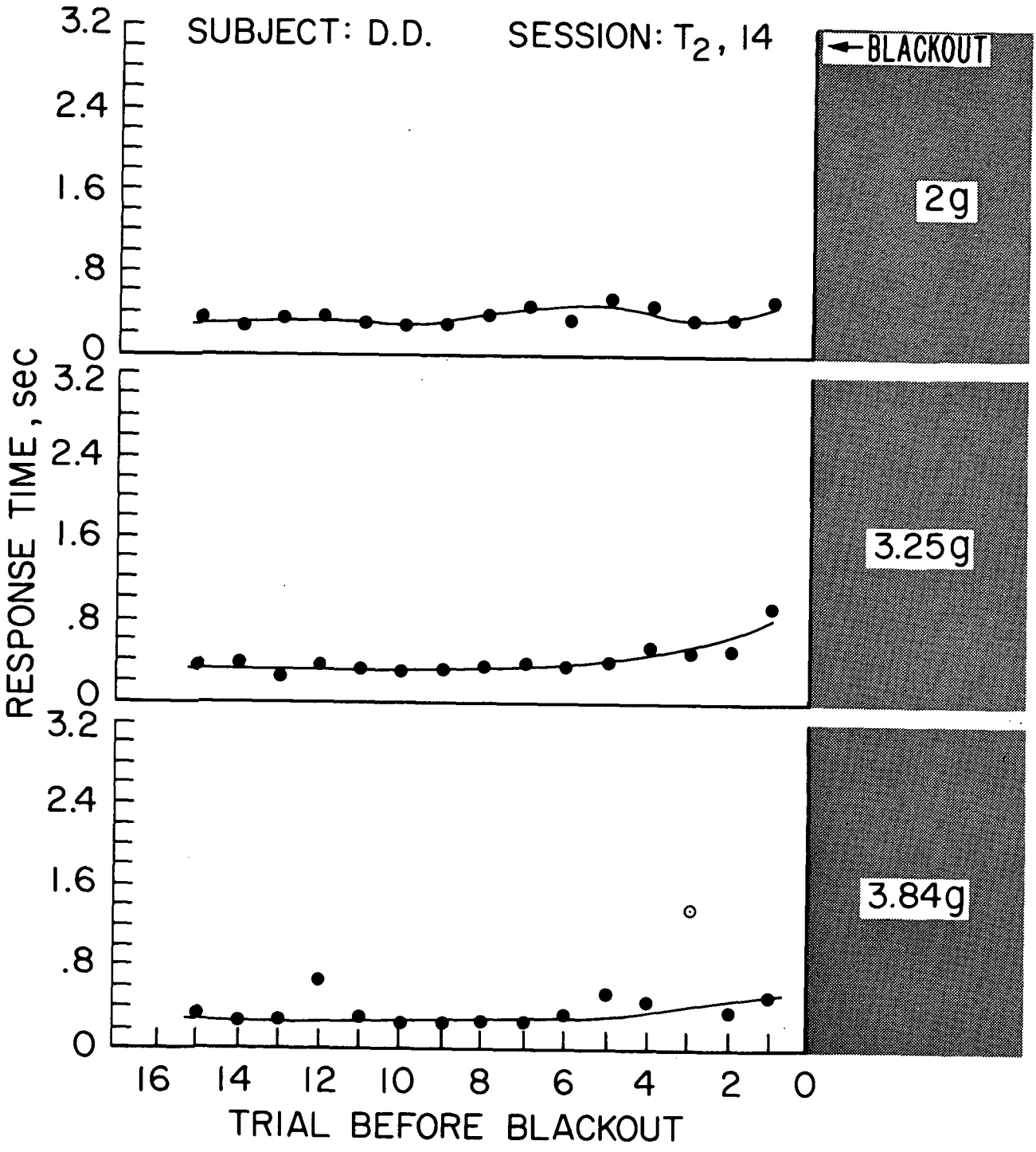

Figure 18. – Trial by trial response times prior to blackout for subject DD, session T_2,14.

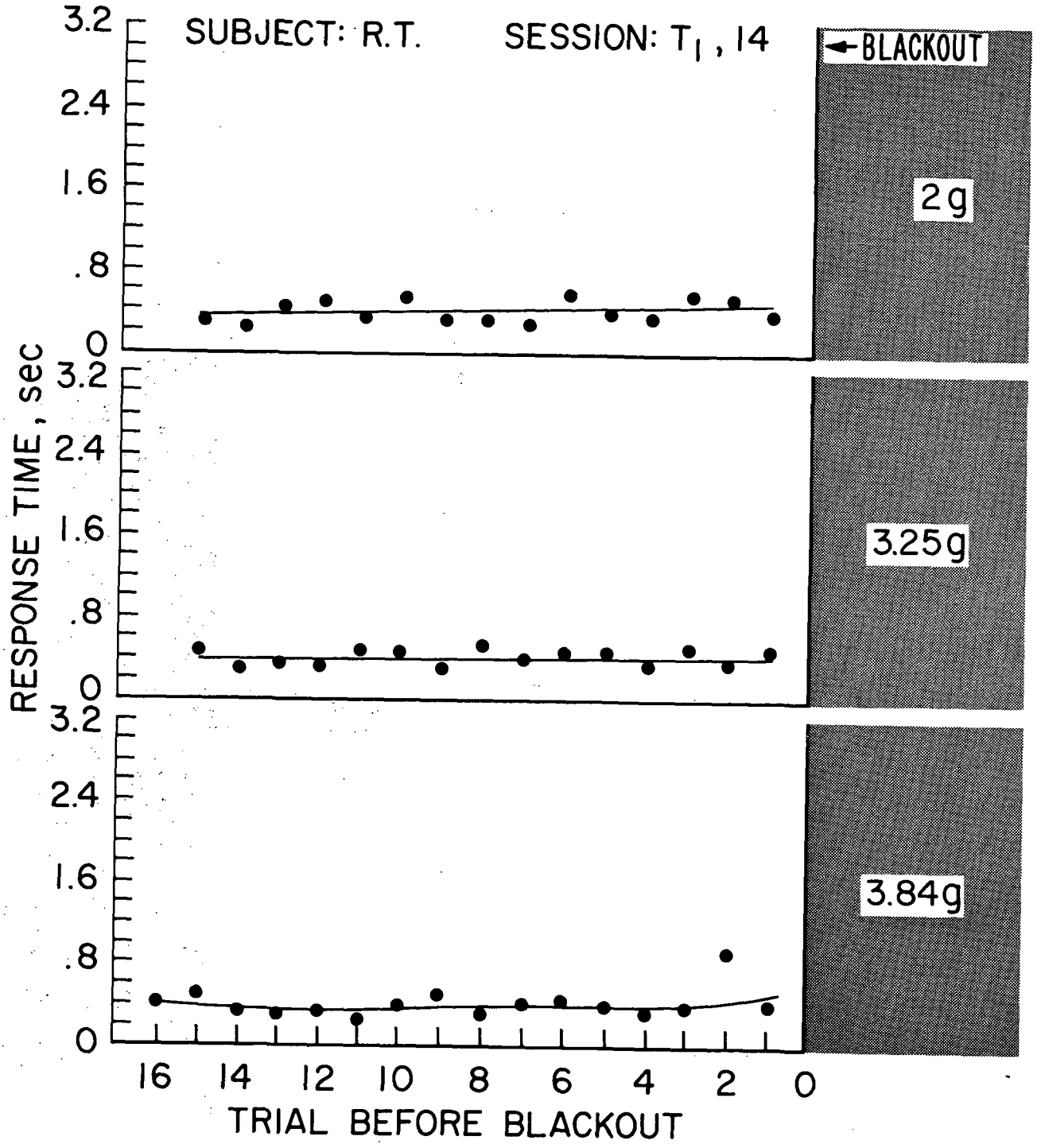

Figure 19. – Trial by trial response times prior to blackout for subject RT, session T_1,14.

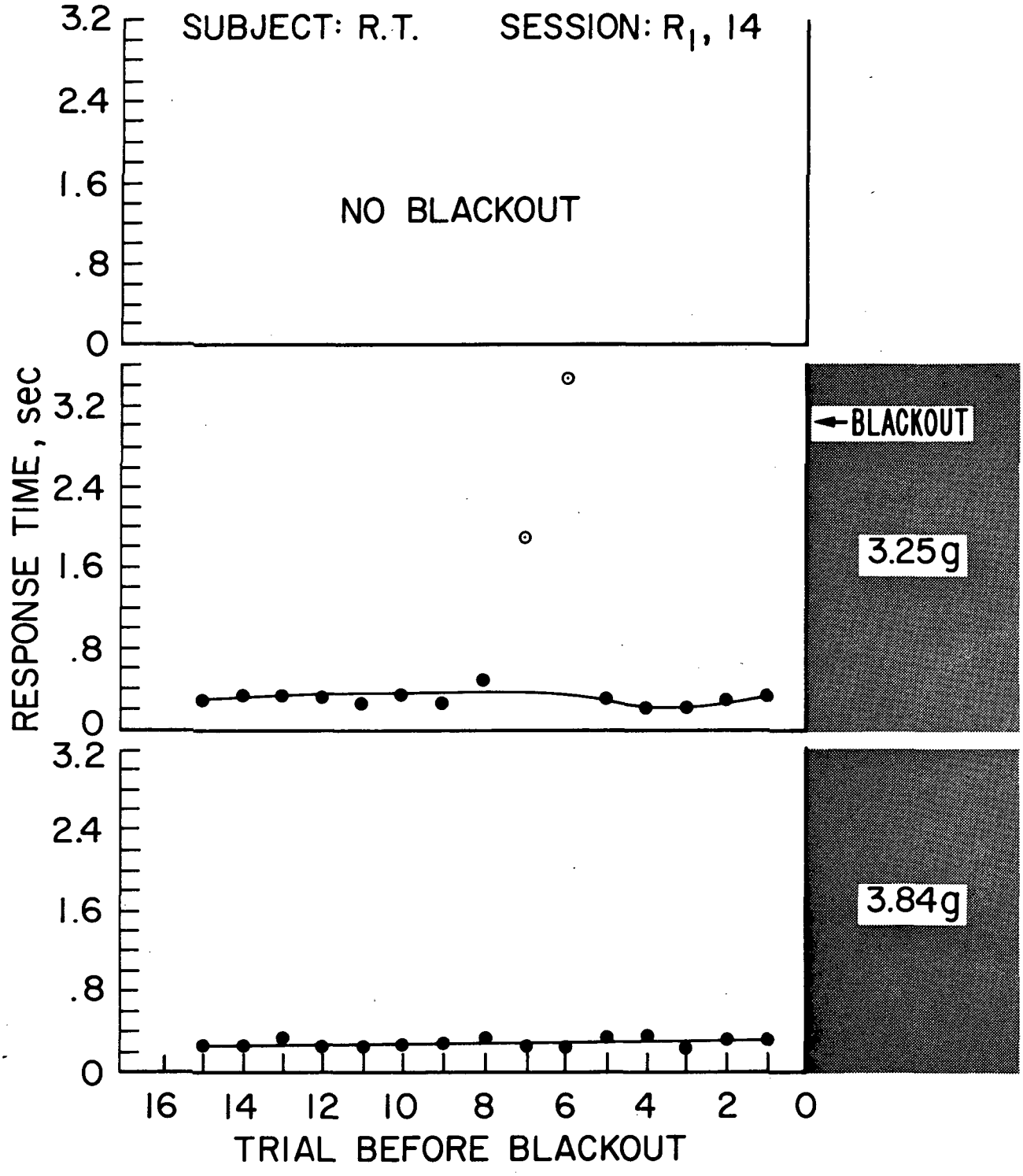

Figure 20. – Trial by trial response times prior to blackout for subject RT, session R_1,14.

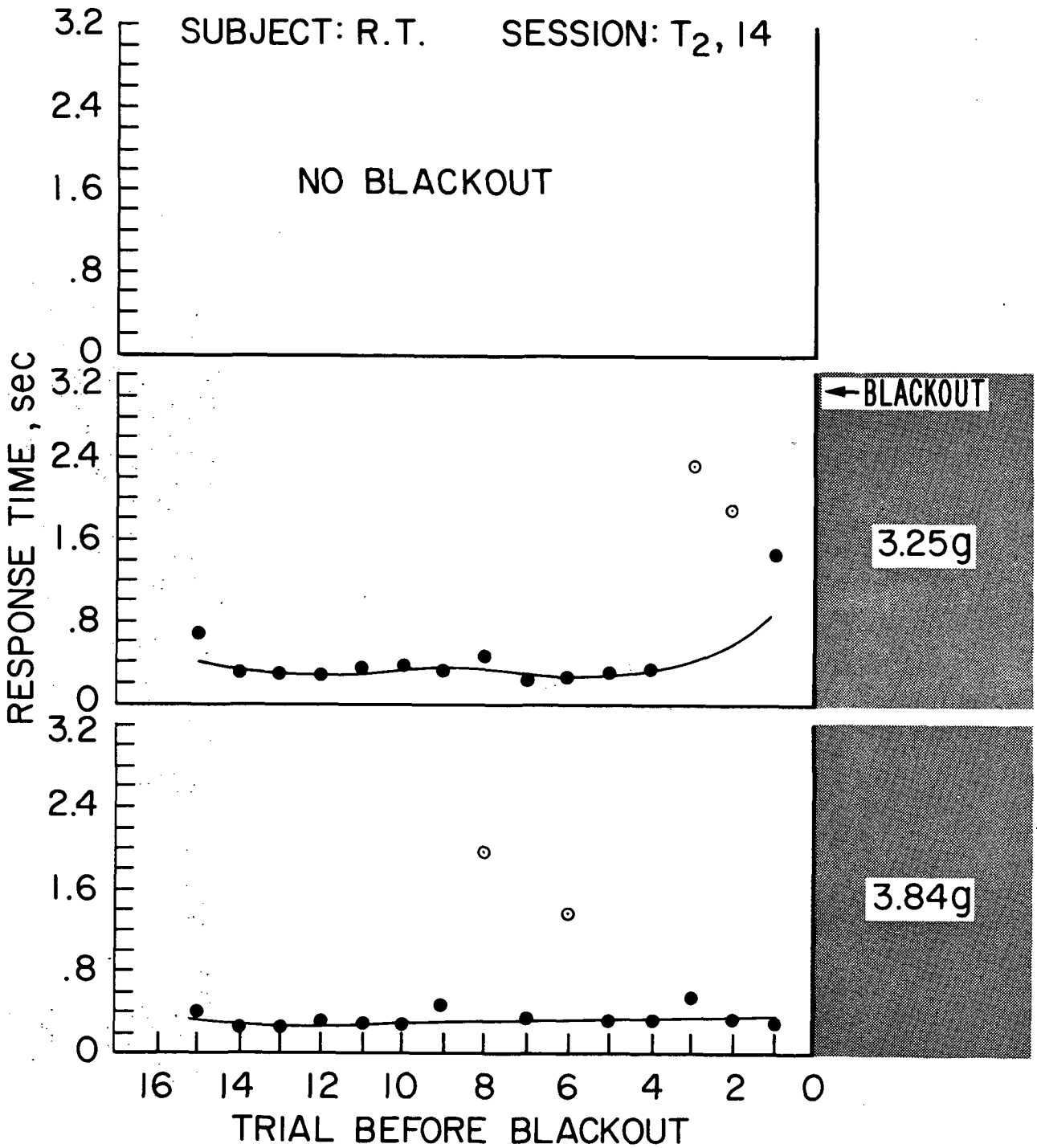

Figure 21. – Trial by trial response times prior to blackout for subject RT, session T_2,14.

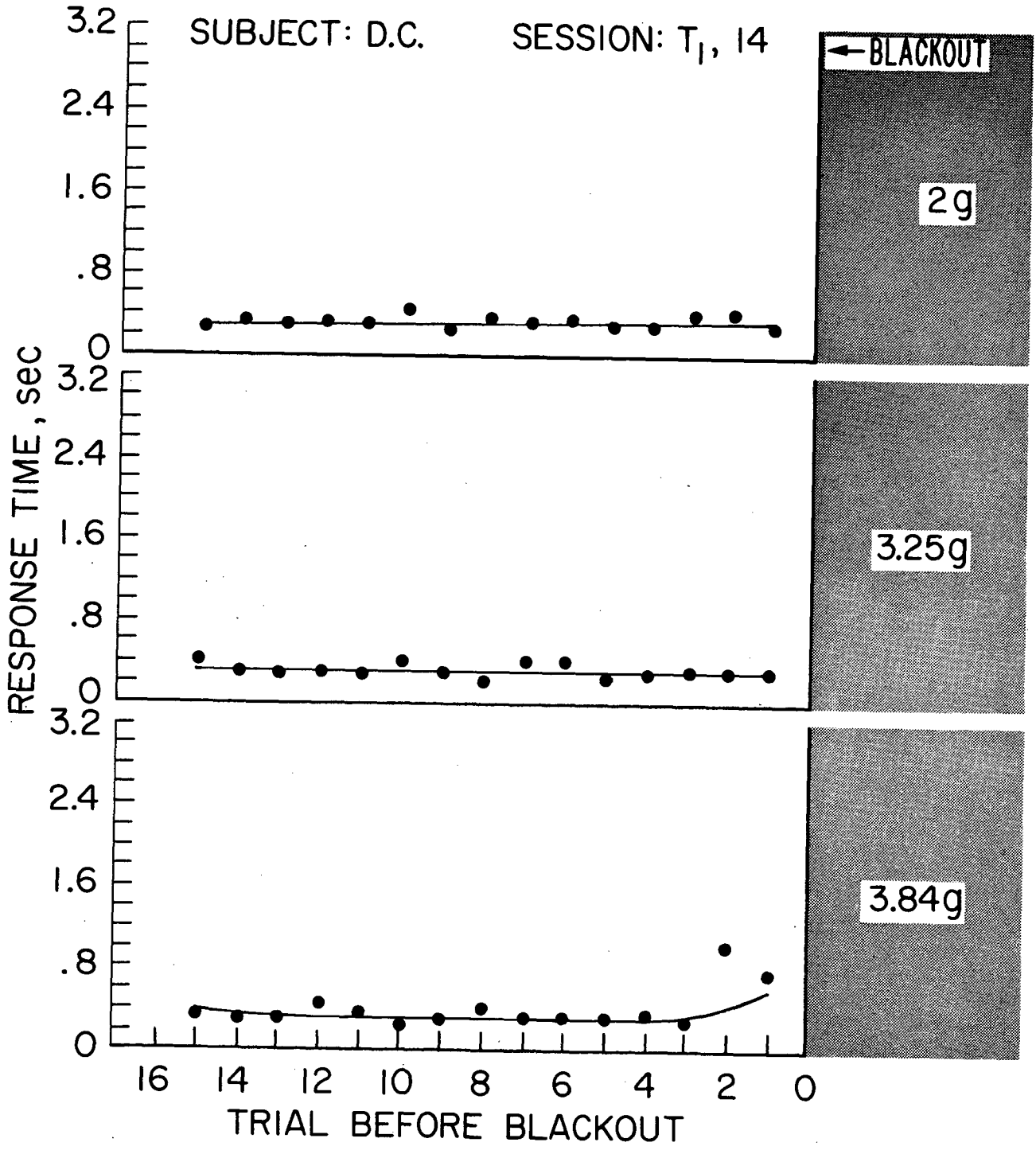

Figure 22. – Trial by trial response times prior to blackout for subject DC, session T_1,14.

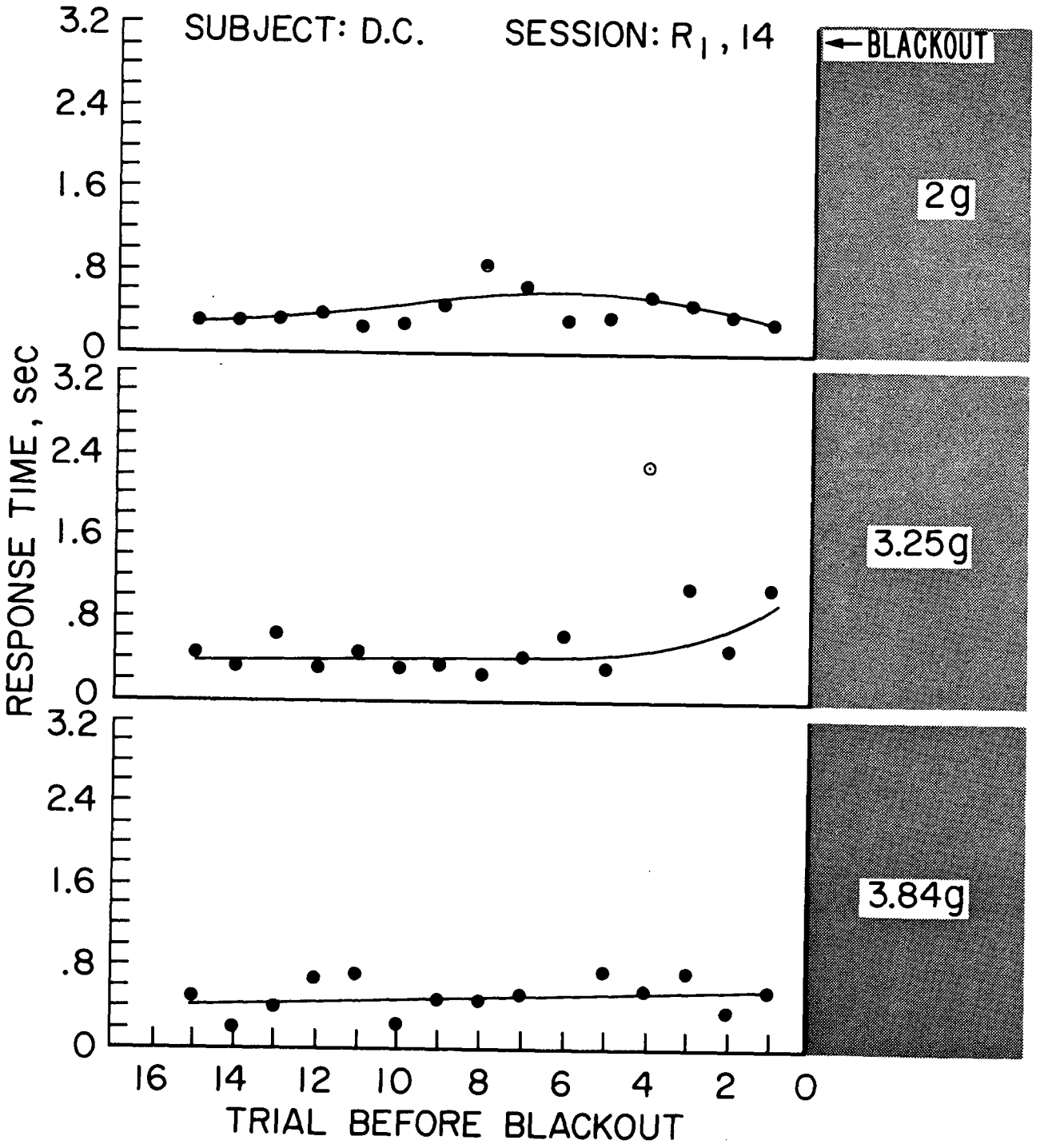

Figure 23. – Trial by trial response times prior to blackout for subject DC, session R_1, 14.

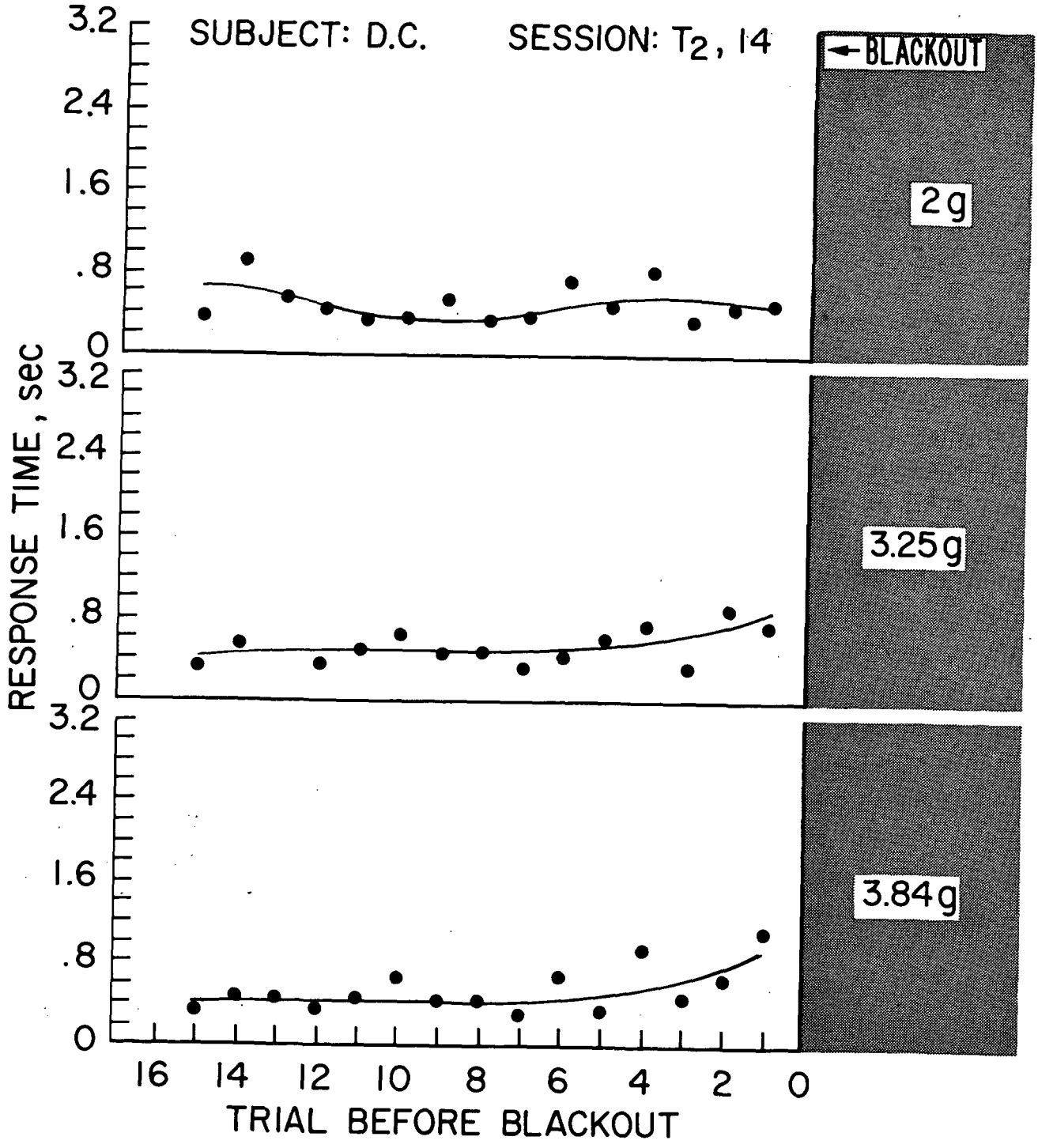

Figure 24. – Trial by trial response times prior to blackout for subject DC, session T_2,14.

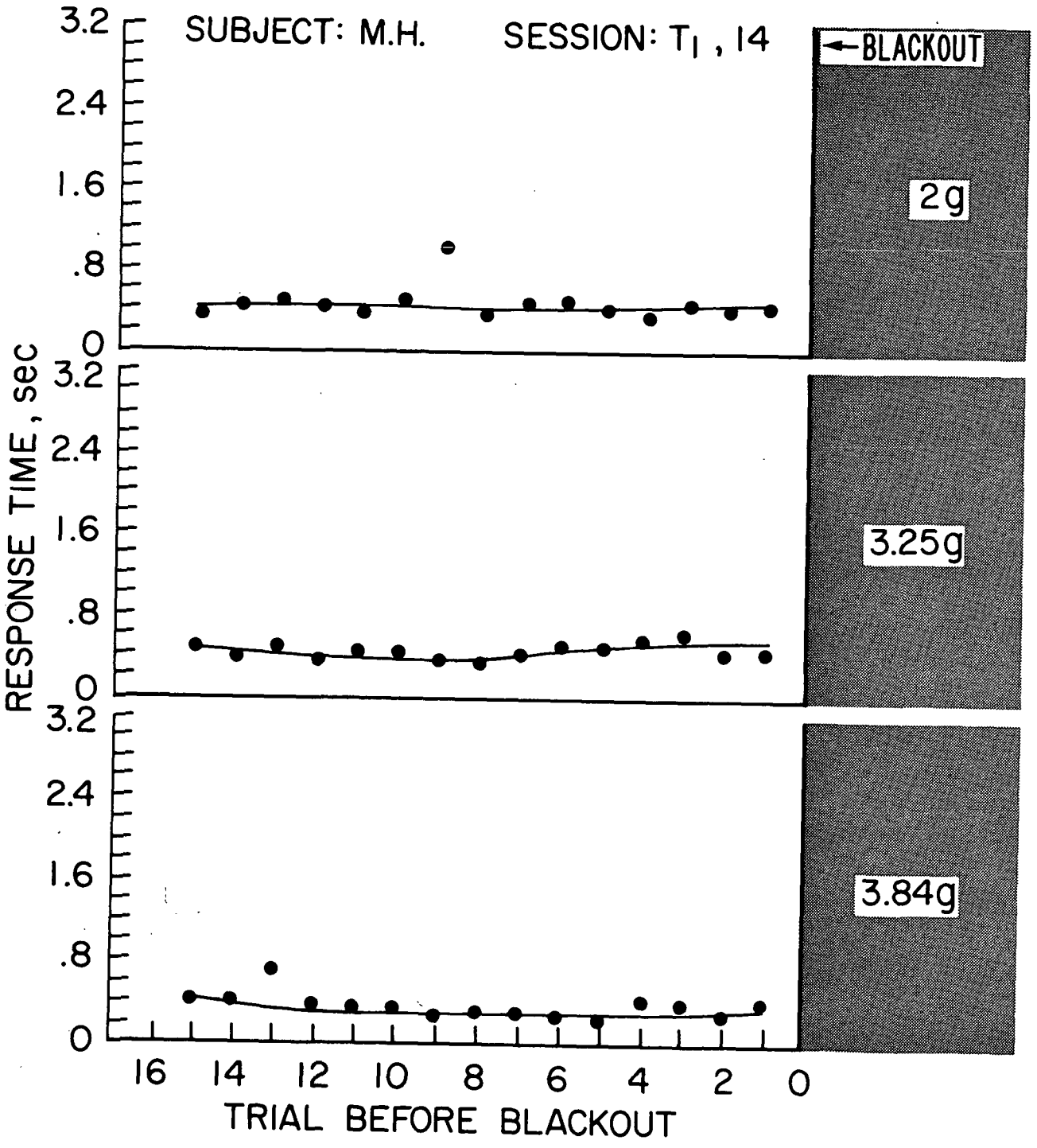

Figure 25. – Trial by trial response times prior to blackout for subject MH, session T_1,14.

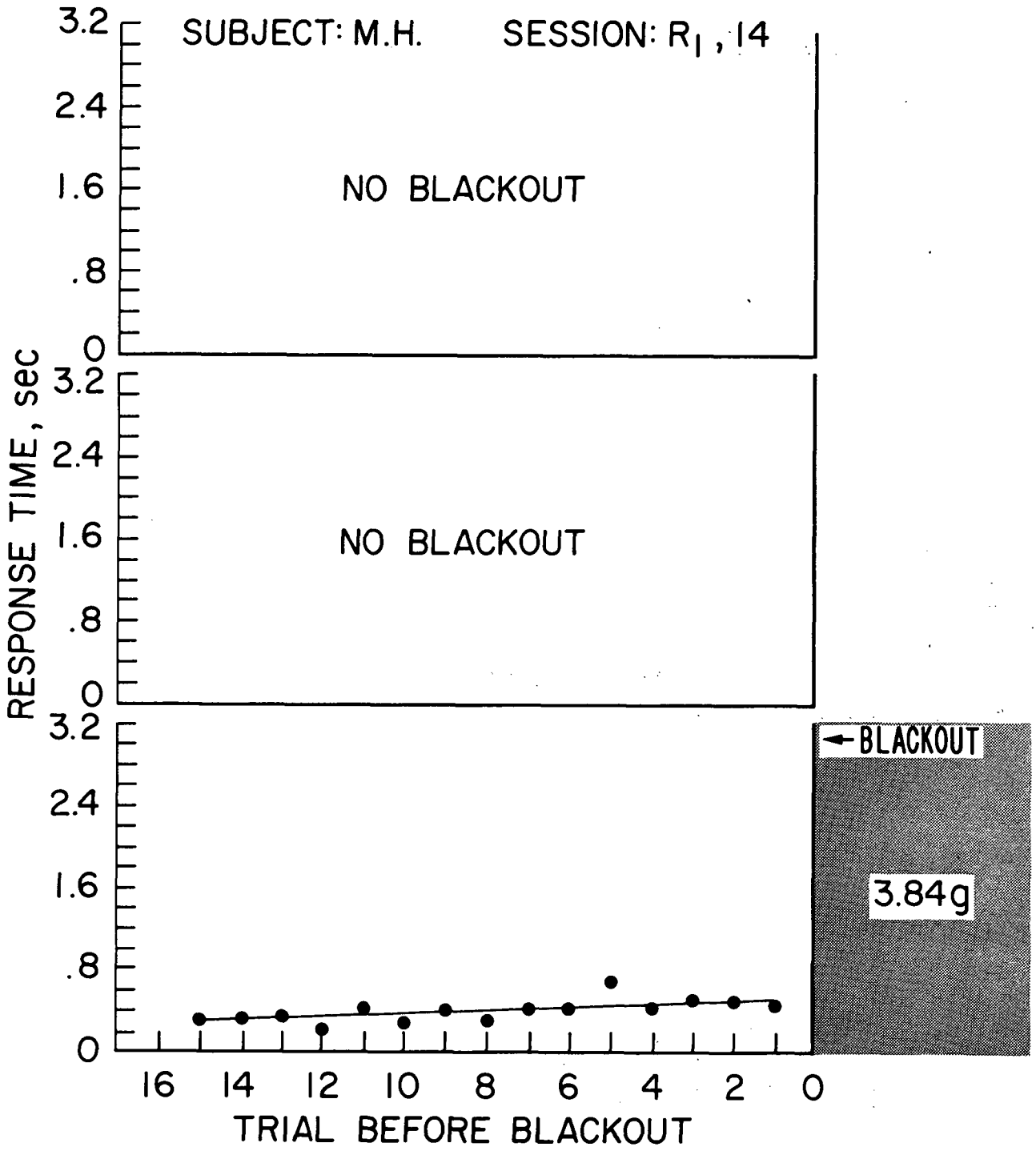

Figure 26. – Trial by trial response times prior to blackout for subject MH, session R_1,14.

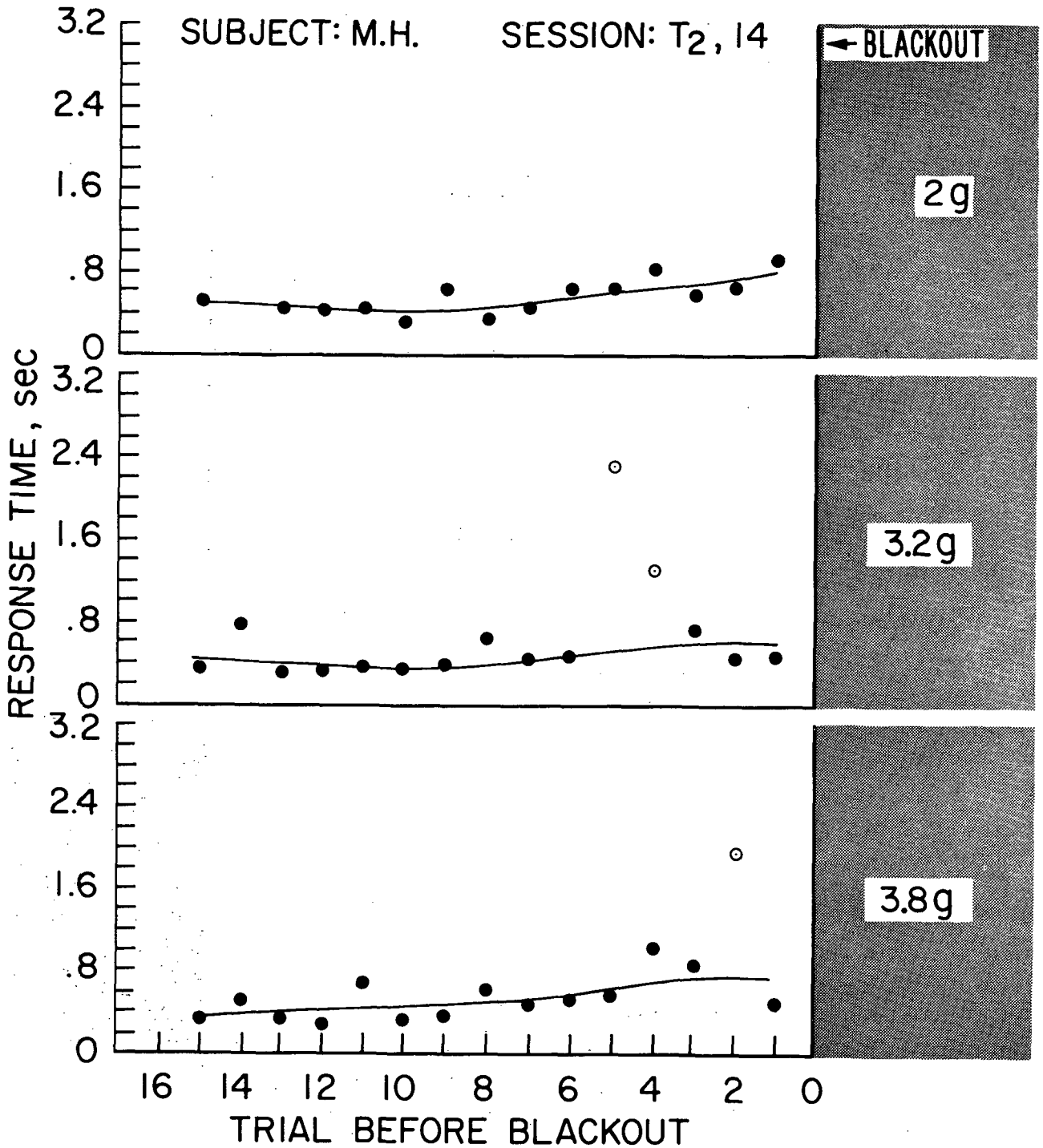

Figure 27. – Trial by trial response times prior to blackout for subject MH, session T_2,14.

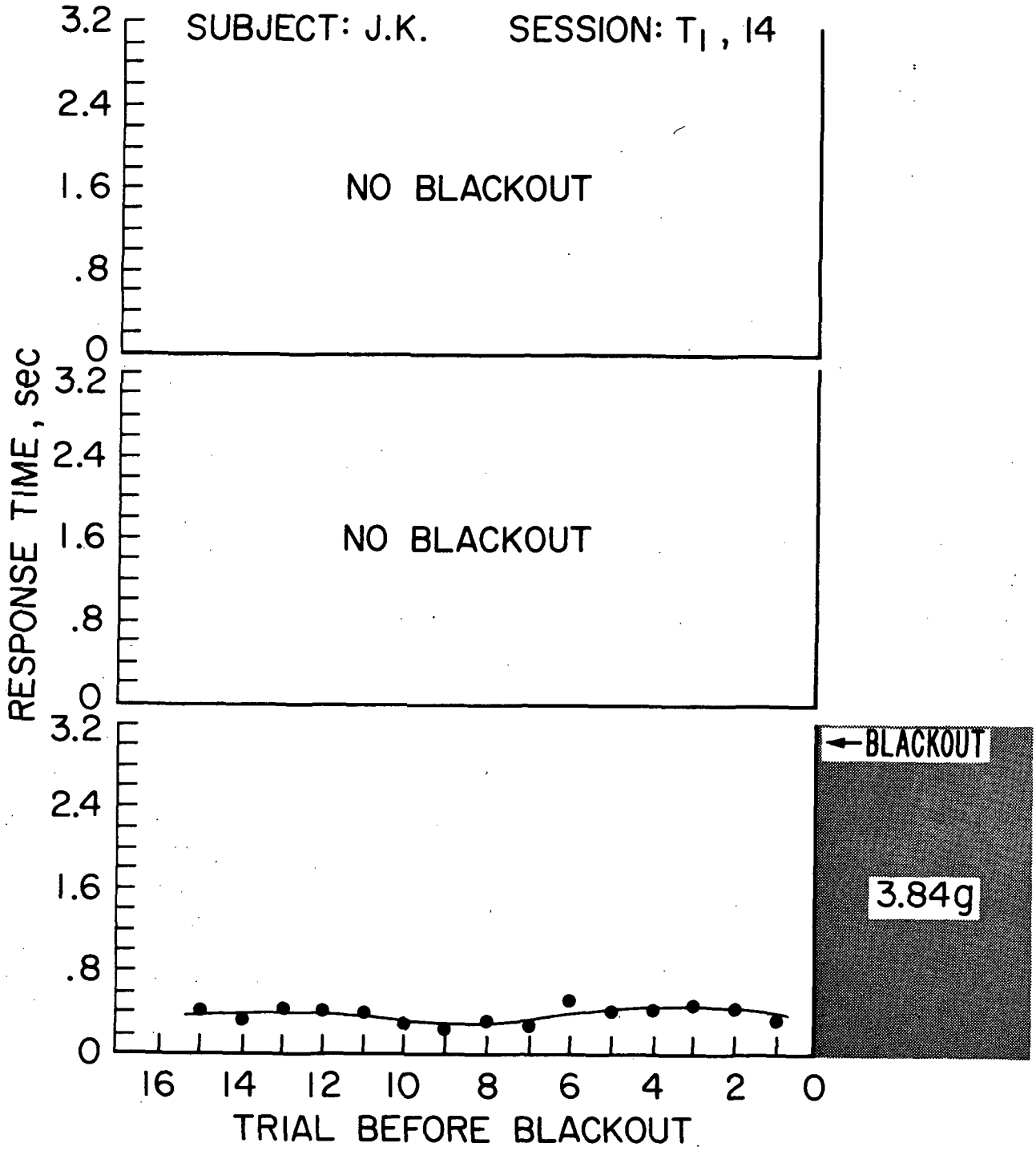

Figure 28. – Trial by trial response times prior to blackout for subject JK, session T_1,14.

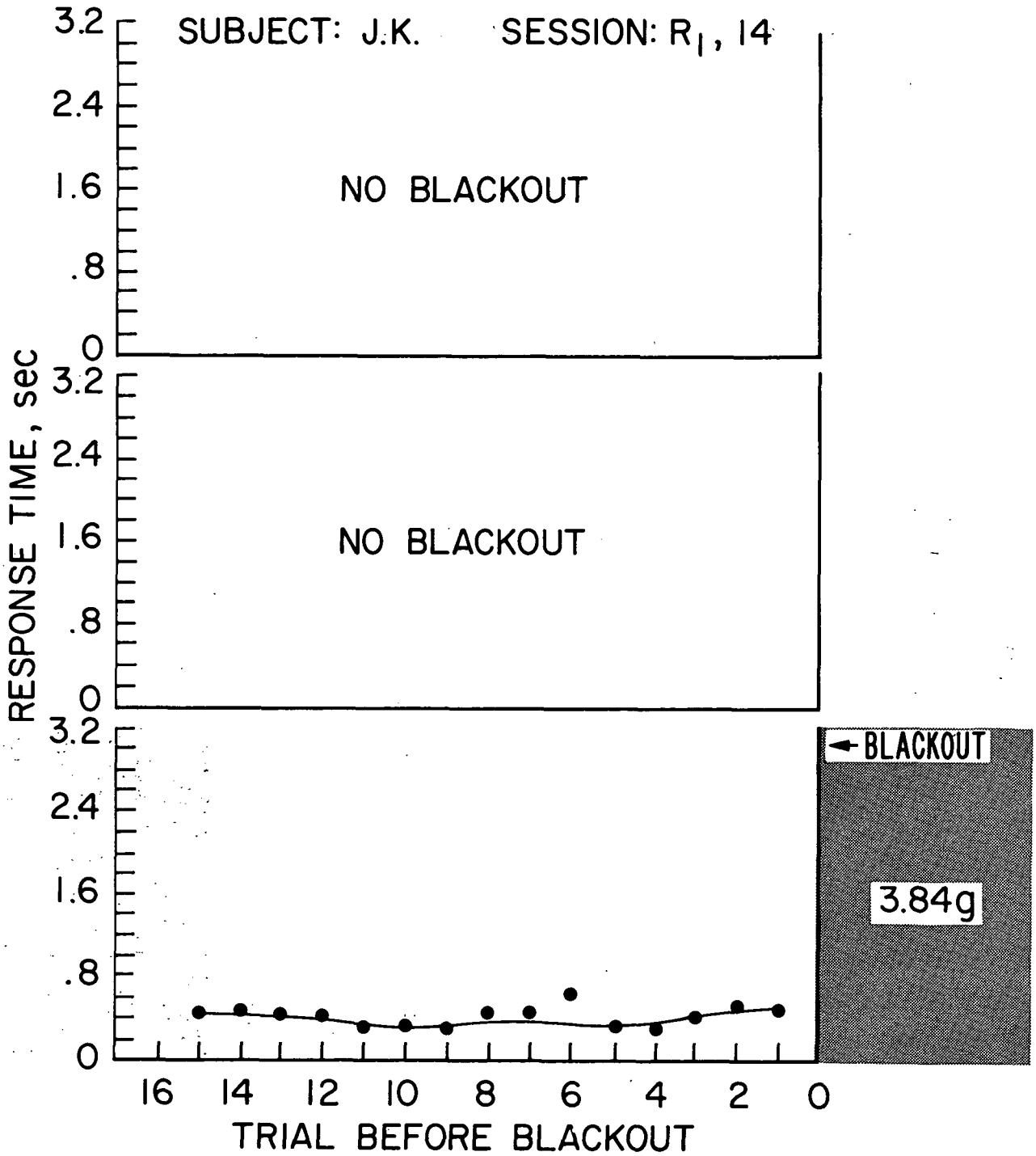

Figure 29. – Trial by trial response times prior to blackout for subject JK, session R_1,14.

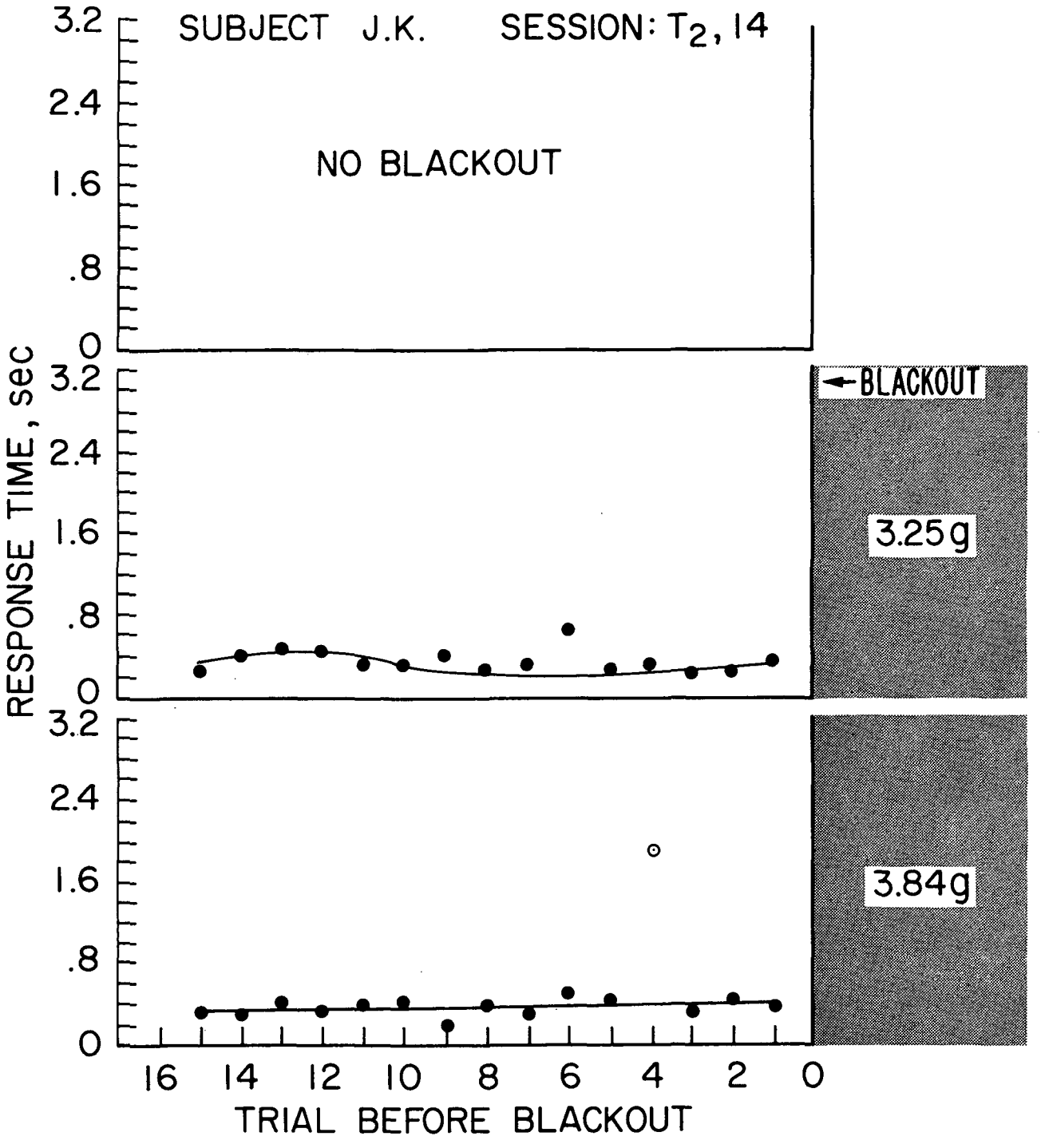

Figure 30. – Trial by trial response times prior to blackout for subject JK, session T_2,14.

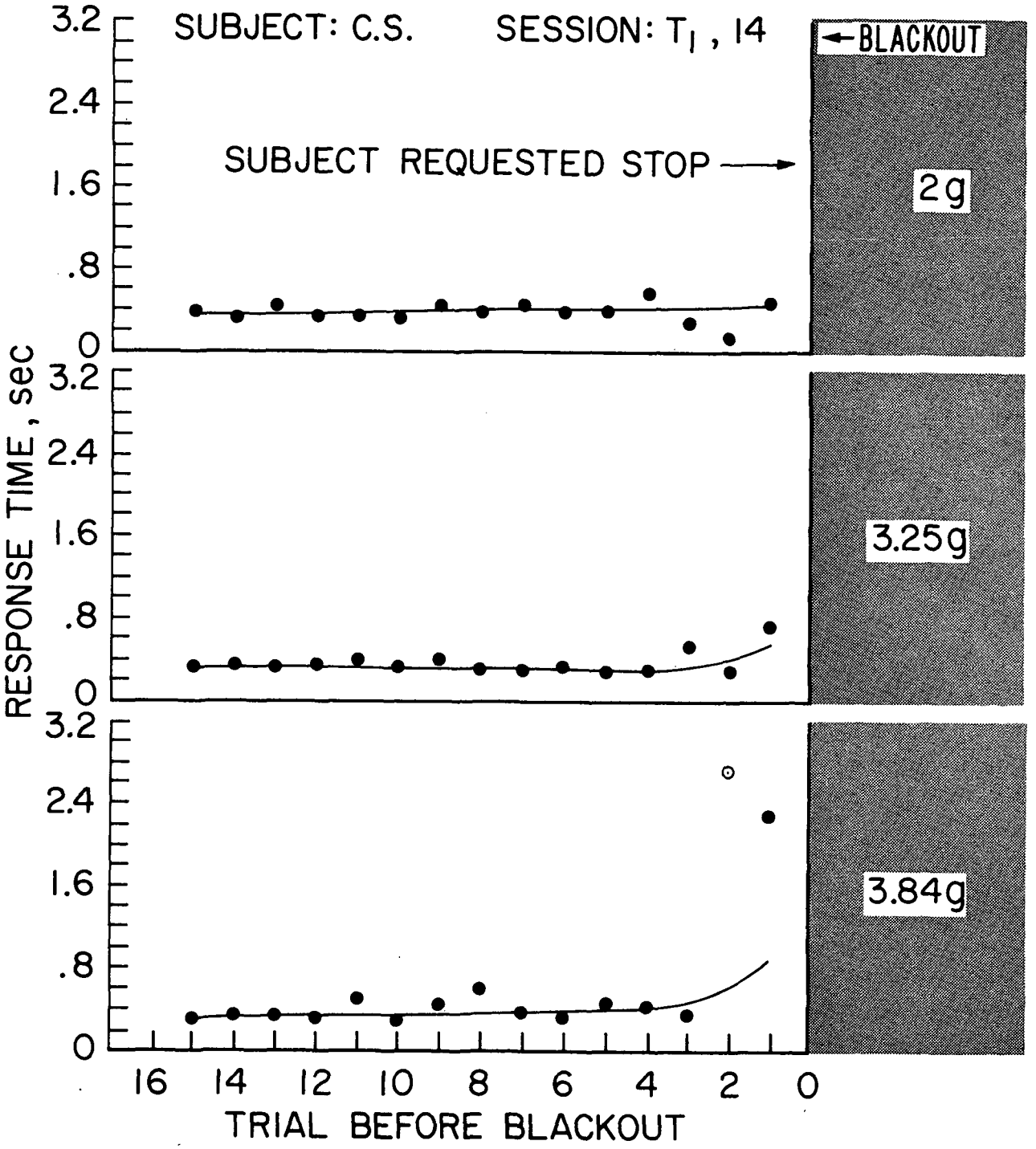

Figure 31. – Trial by trial response times prior to blackout for subject CS, session T_1,14.

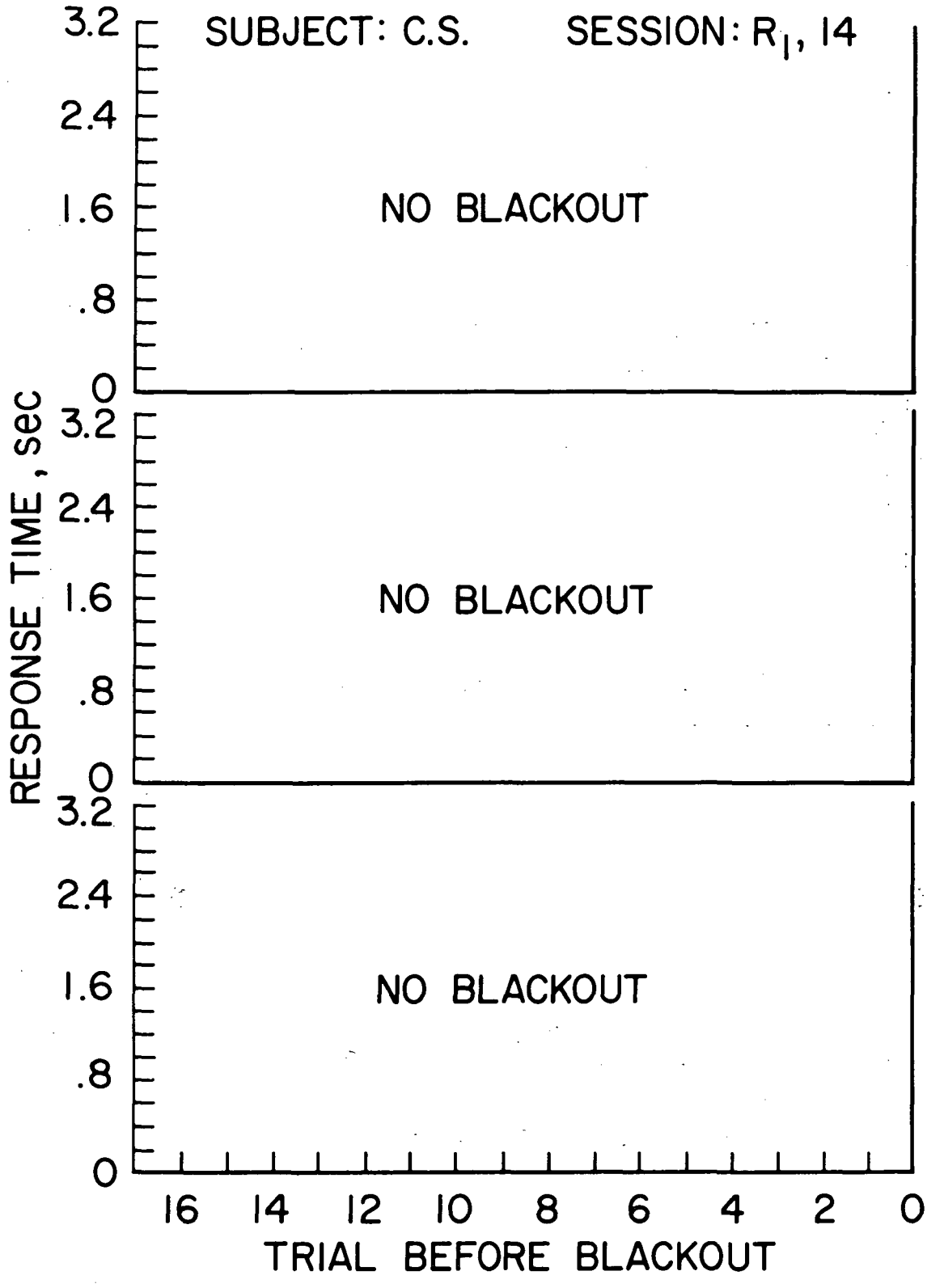

Figure 32. – Trial by trial response times prior to blackout for subject CS, session R_1,14.

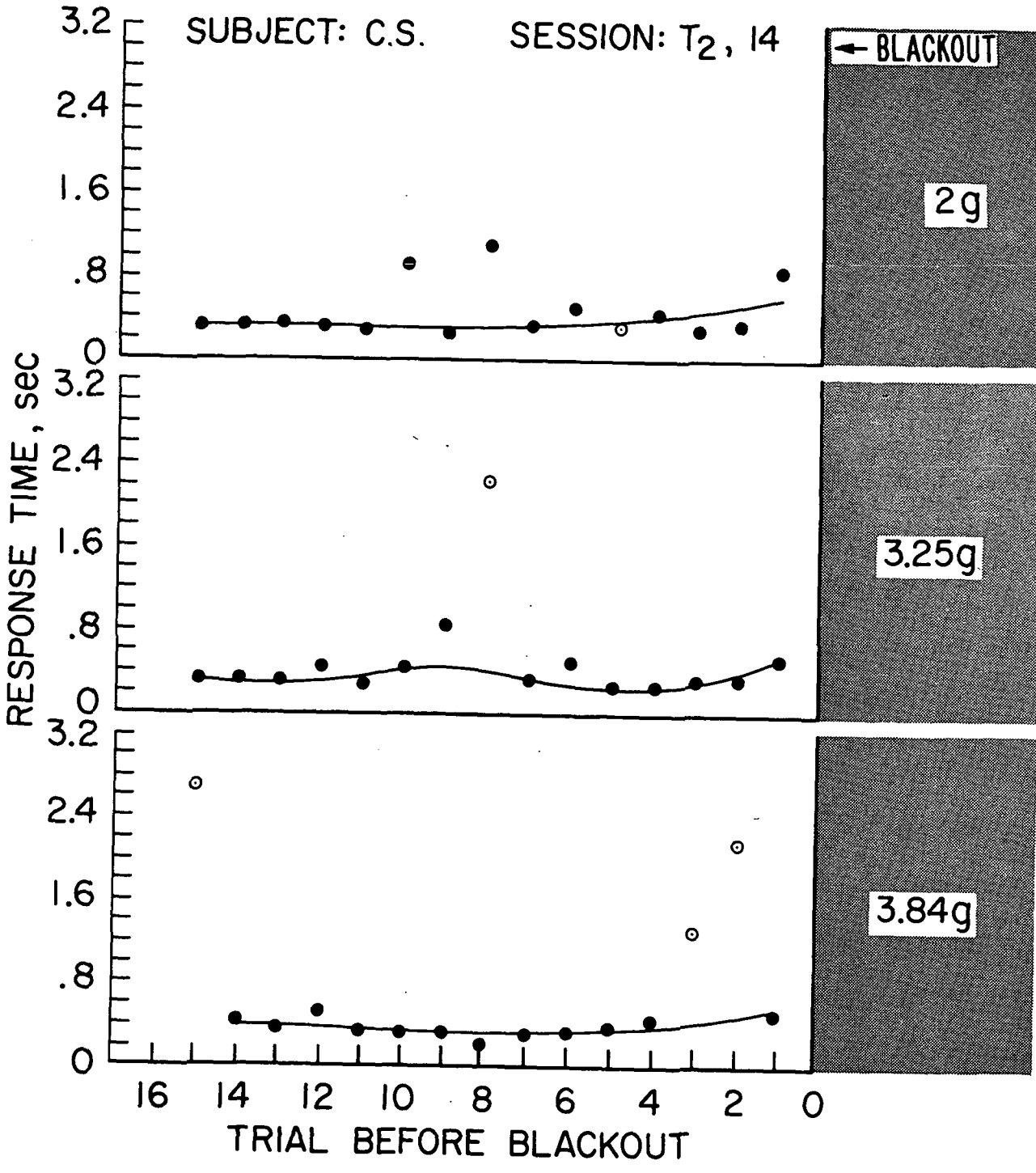

Figure 33. – Trial by trial response times prior to blackout for subject CS, session T_2,14.

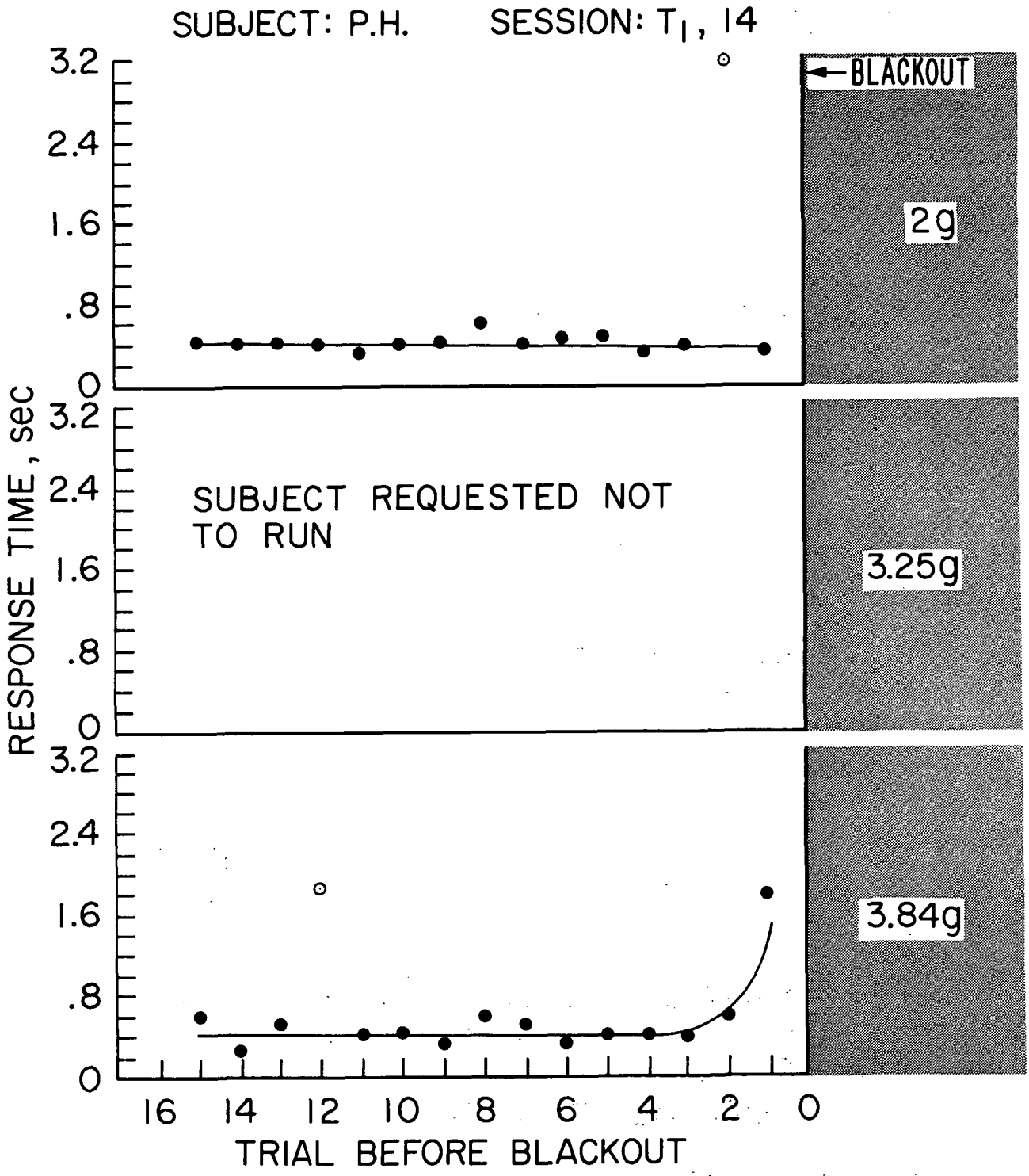

Figure 34. – Trial by trial response times prior to blackout for subject PH, session T_1,14.

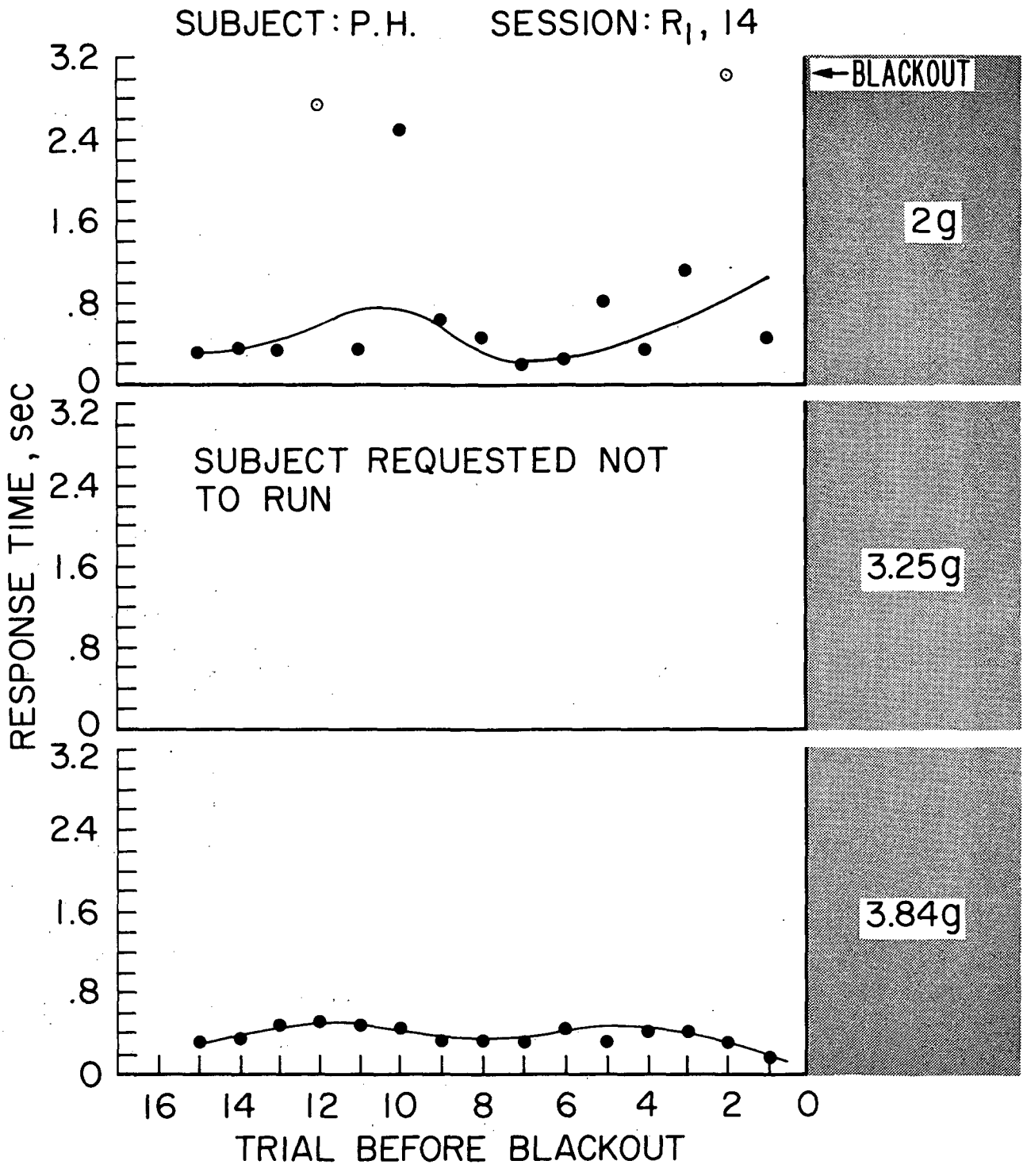

Figure 35. – Trial by trial response times prior to blackout for subject PH, session T_2,14.

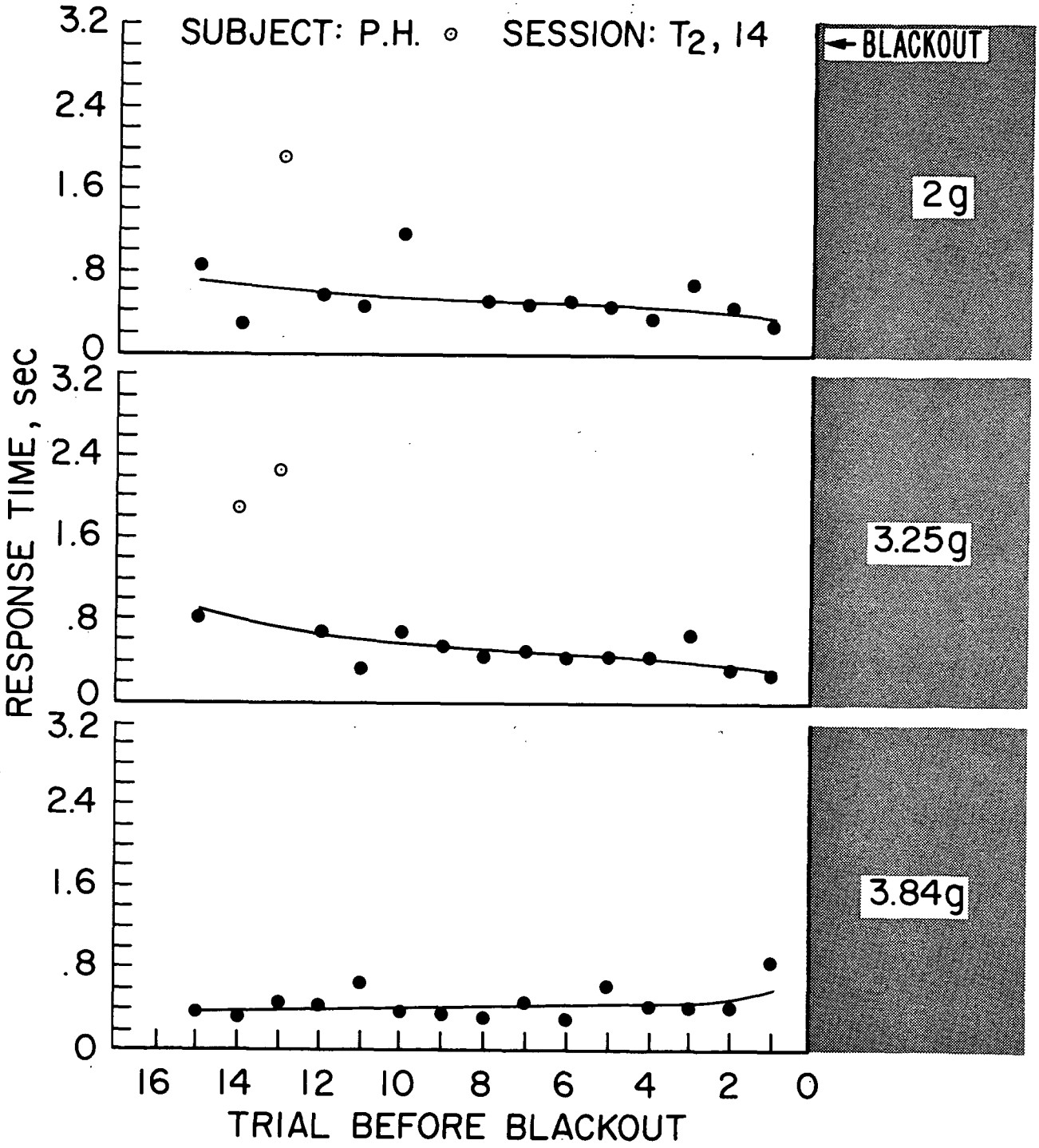

Figure 36. – Trial by trial response times prior to blackout for subject PH, session T_2,14.

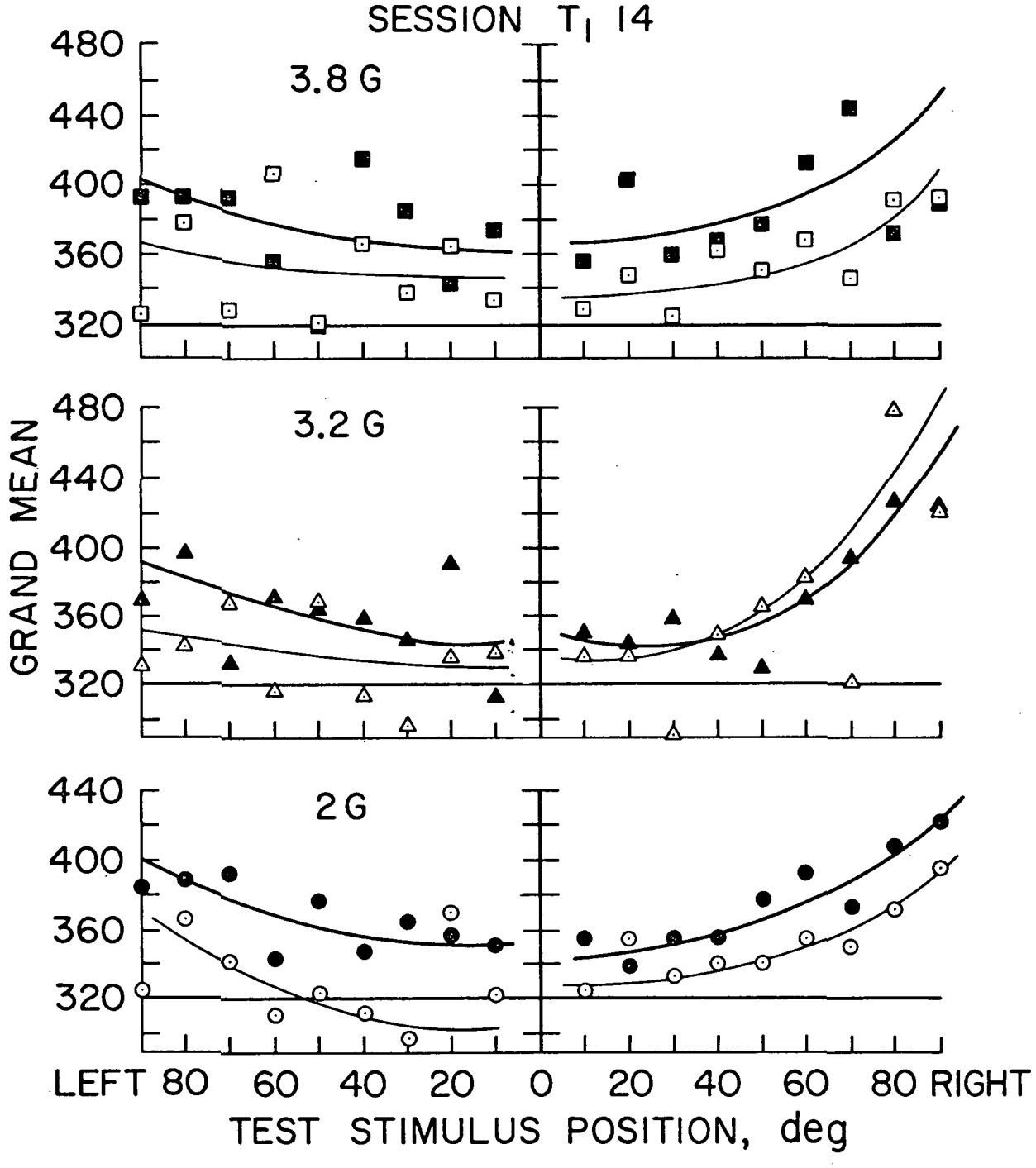

Figure 37. – Grand mean $+G_z$ acceleration response time data averaged across subjects and days within sessions, session T_1,14.

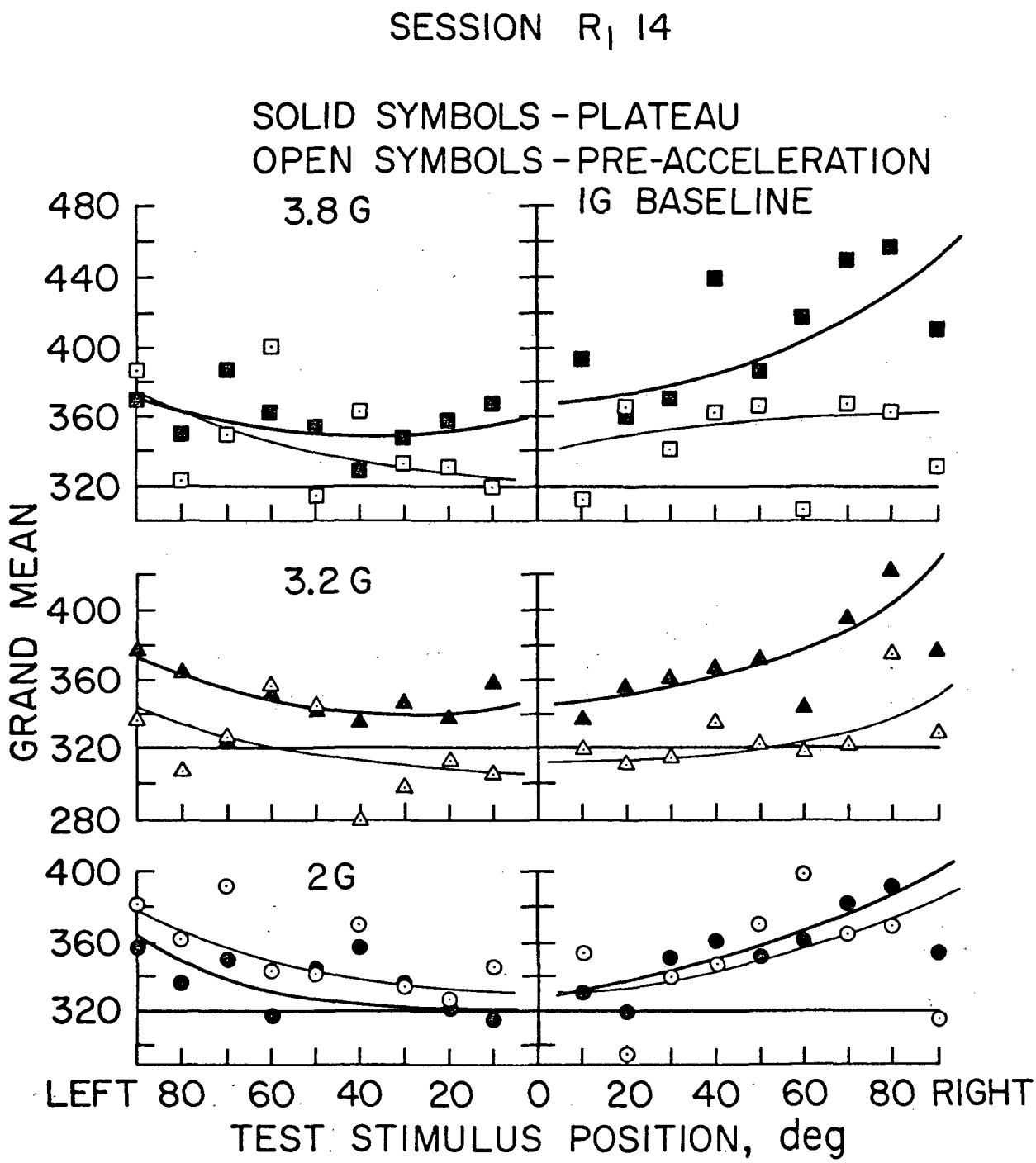

Figure 38. – Grand mean $+G_Z$ acceleration response time data averaged across subjects and days within sessions, session R_1,14.

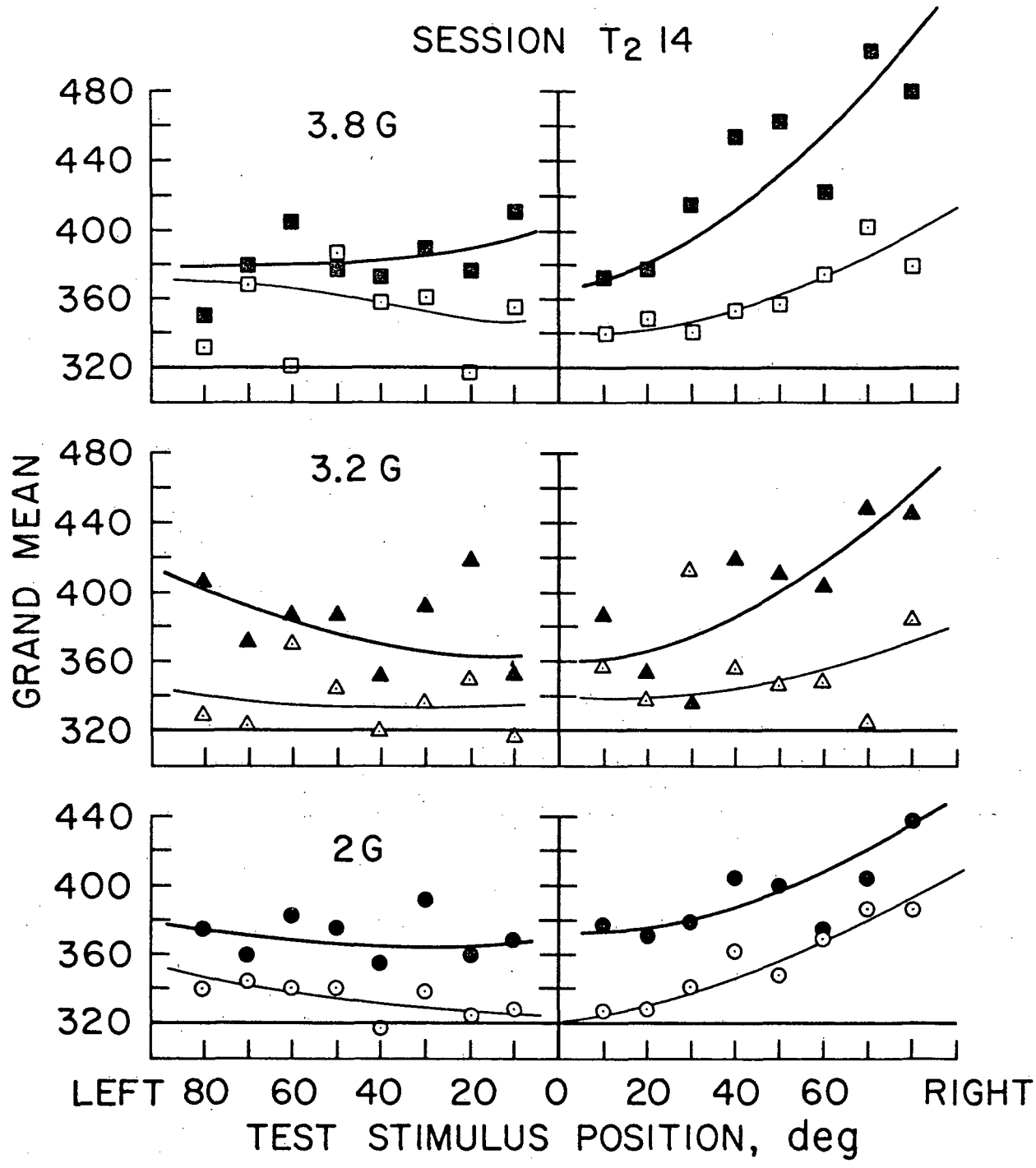

Figure 39. – Grand mean $+G_z$ acceleration response time data averaged across subjects and days within sessions, session T_2,14.

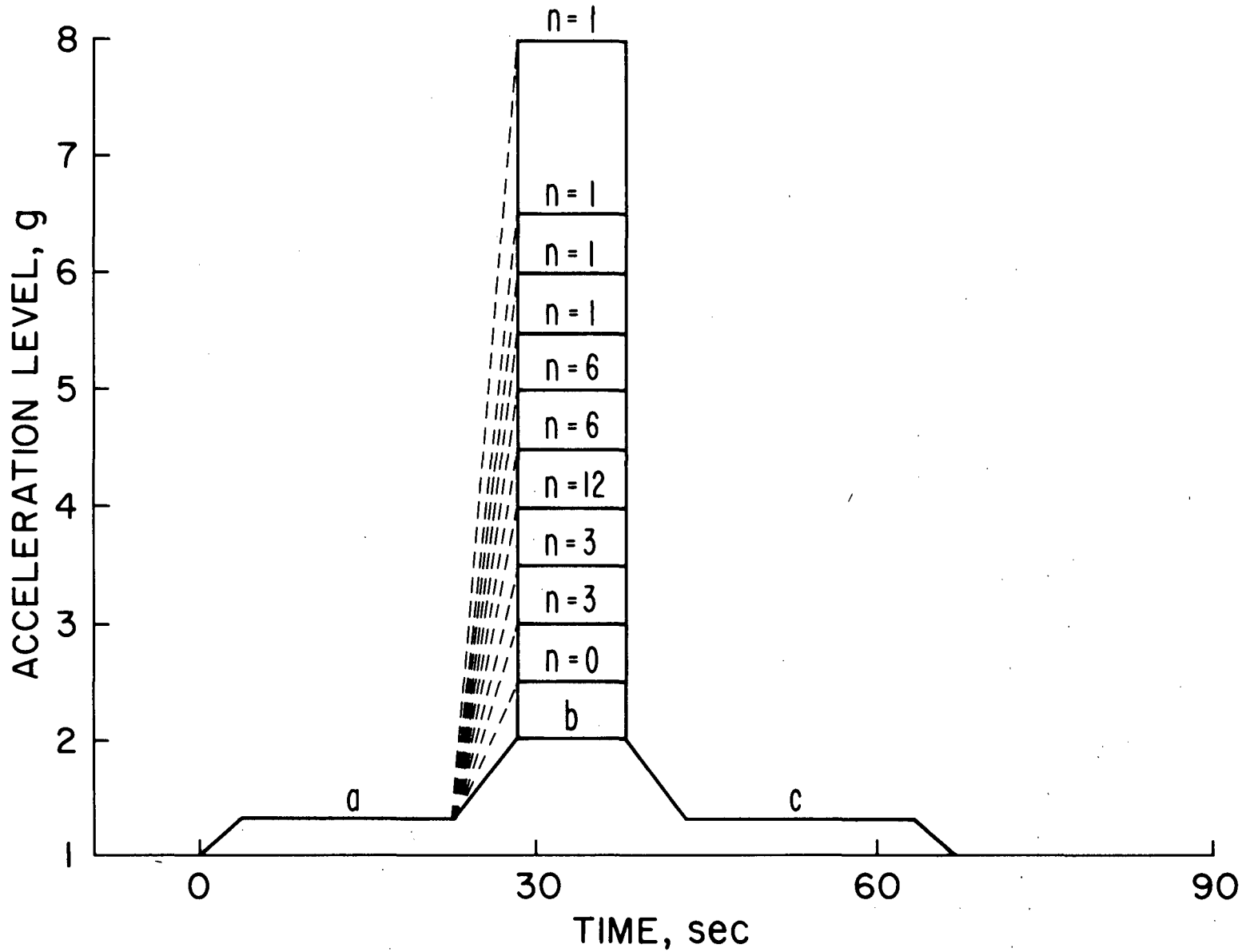

Figure 40. – Acceleration profile used by Kennedy, Kerr, Russell, and Franks (ref. 41).

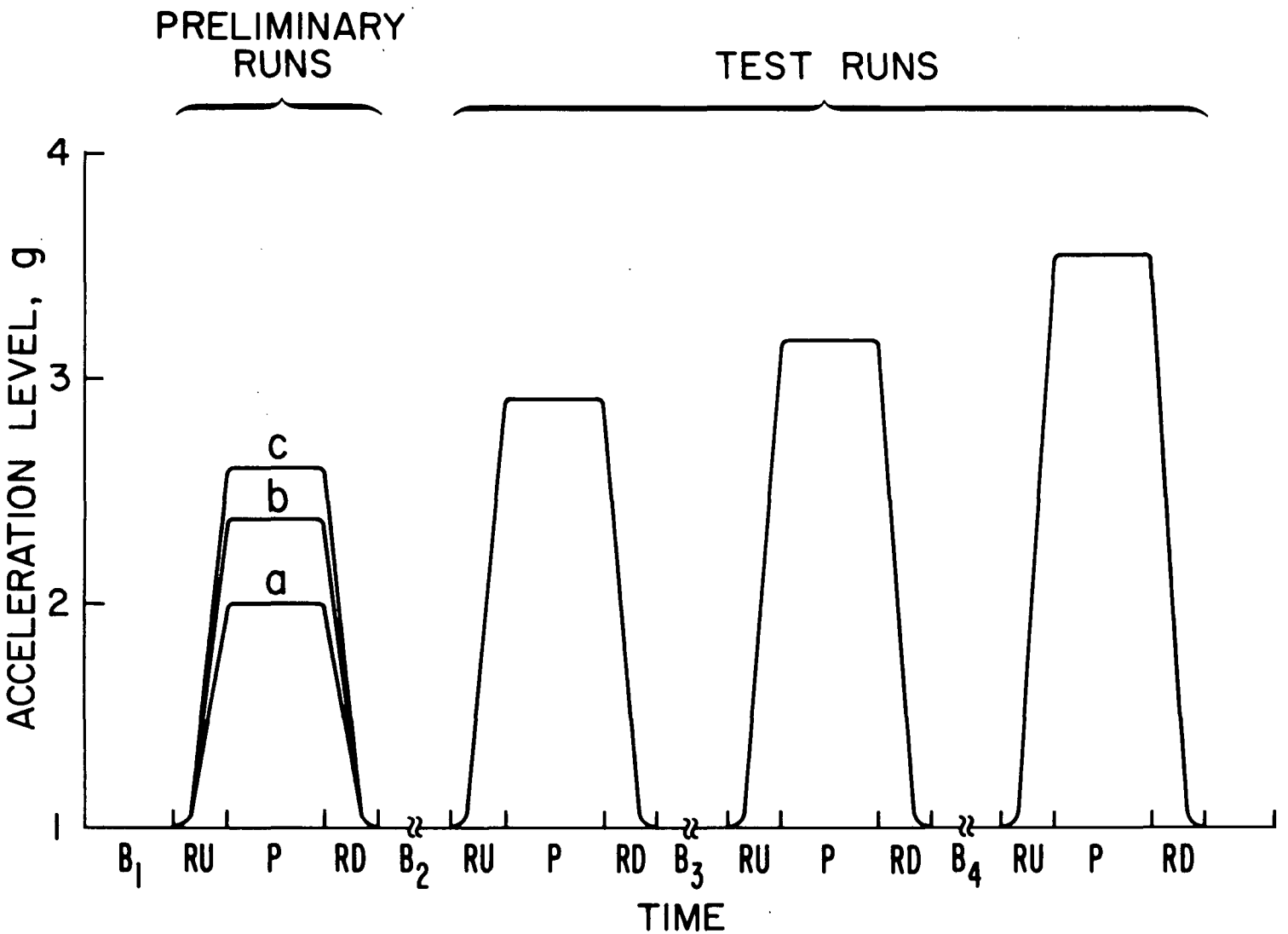

Figure 41. – Acceleration profile used by Brown and Burke (ref. 19).

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